MAN AND HIS PHYSICAL UNIVERSE

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MAN

AND HIS PHYSICAL UNIVERSE

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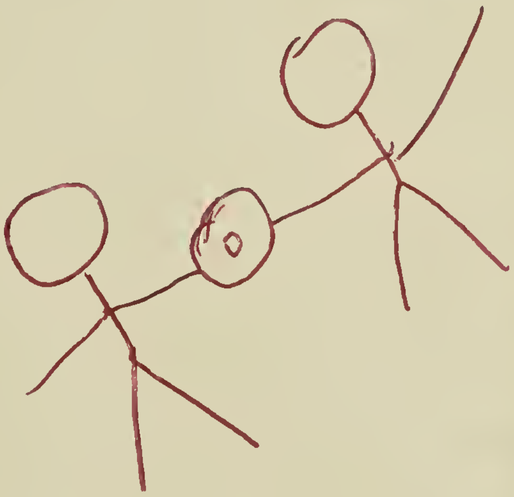

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PREFACE

Scientific discoveries and their application to the needs of modern life have been the outstanding achievements of the twentieth century. Home relationships, public health, social institutions, industrial problems, and foreign affairs have all been influenced in a vital way by them. That these advances should also affect educational theory and practice was inevitable. Consequently educators early recognized the importance of giving science a prominent place in the college program. To this end special courses of a general nature within each of the specific fields were formulated, and either designated courses or elections from groups of these courses came to be required.

At the outset high hopes as to the educational results of such a policy were entertained. But the actual outcomes of these traditional courses proved disappointing. In most instances the subject matter in each field was selected by a specialist and organized in accordance with his point of view. This policy often resulted in more or less detailed, descriptive courses that left the student in possession of certain specific facts but without an adequate understanding of the application of those facts to the needs of life.

Because of these inadequacies, especially for the student who does not intend to specialize in the field of science, there has been a more or less pronounced reaction on the part of progressive science teachers and informed educational administrators. They are demanding courses that cut across many sciences. They are calling for courses which develop the understandings that will help the student to locate himself in his universe; that will free him from superstition and prejudice; that will impress him with the importance of relying upon established truth in ordering his own life; and that will enable him to appreciate the careful, logical methods employed by scientists in arriving at trustworthy conclusions. In short, these educators are insisting upon courses in which the generalizations and understandings of science shall be developed in such a way as to influence significantly the beliefs, philosophy, behavior, and attitudes of the future citizens of our democracy.

The text *Man and the Nature of His Physical Universe* was produced to meet the needs of such a program. During the seven years that have intervened the trend toward science-survey courses in colleges and universities has become accelerated. Consequently this revision, *Man and His Physical Universe*, is made to bring the book up to date and to correct such inadequacies as have been revealed through use.

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CONTENTS

UNIT ONE · MAN'S INCREASED KNOWLEDGE OF THE COSMOS HAS MODIFIED HIS THINKING

PAGE

CHAPTER ONE · *Ancient Man's Limited Knowledge of the Heavens Led to Erroneous Conclusions* 5

CHAPTER TWO · *The Study of the Heavens Has Been Advanced by the Application of the Scientific Method* 14

CHAPTER THREE · *Knowledge of the Heavens Has Been Extended through the Use of Astronomical Instruments* 22

CHAPTER FOUR · *Investigation with Astronomical Instruments Has Changed Man's Understanding of the Stars* 37

CHAPTER FIVE · *The Study of Nebulae Has Expanded Man's Ideas of Space* 57

CHAPTER SIX · *The Sun Is a Tumultuous Body Whose Radiations Bombard the Earth* 68

CHAPTER SEVEN · *Astronomical Study Has Changed Man's Conception of the Solar System* 88

CHAPTER EIGHT · *Superstitions regarding Comets and Meteors Have Been Displaced by Scientific Knowledge* 114

CHAPTER NINE · *Astronomical Bodies Enable Man to Determine Time* 127

UNIT TWO · THE FUNDAMENTAL DISTINCTION FORMERLY SUPPOSED TO EXIST BETWEEN MATTER AND ENERGY HAS BEEN BROKEN DOWN

CHAPTER TEN · *Matter Is Considered to Be But a Special Form of Energy* 137

CHAPTER ELEVEN · *Man Has Made Other Valuable Discoveries as to the Nature and Constitution of Matter* 160

UNIT THREE · MATTER AS ORGANIZED ENERGY POSSESSES PROPERTIES WHICH ARE INDISPENSABLE TO MAN

CHAPTER TWELVE · *Matter May Be Changed from One State to Another* 173

CHAPTER THIRTEEN · *The New Concept of Matter Explains Many Aspects of Chemical Behavior* 192

PAGE
CHAPTER FOURTEEN · *Chemical Changes Depend on the Physical Conditions and the Chemical Nature of Substances* 205
CHAPTER FIFTEEN · *Organic and Colloidal Chemistry Are Involved in Life Processes and in Many Reactions of Value to Man* 218
CHAPTER SIXTEEN · *Chemical Products Have Added to the Convenience and Pleasure of Living* 236

UNIT FOUR · ENERGY IN MANY FORMS IS USED BY MAN TO ADVANCE CIVILIZATION

CHAPTER SEVENTEEN · *The Earth Is Flooded with Energy, of Which Heat Is a Form Indispensable to Man* 267
CHAPTER EIGHTEEN · *Heat Is Applied in Many Different Ways for the Convenience and Comfort of Living* 291
CHAPTER NINETEEN · *Magnetism and Electricity Have Changed the Life of Man* 316
CHAPTER TWENTY · *The Applications of Electricity Are Numerous* 351
CHAPTER TWENTY-ONE · *Energy May Take the Form of Radiations* 363
CHAPTER TWENTY-TWO · *Radiant Energy Has a Wide Range of Application* 378
CHAPTER TWENTY-THREE · *Electrical Energy and Radiant Energy Have Made Possible the Electric Light and the Airplane* 410
CHAPTER TWENTY-FOUR · *Sound Is Propagated by Waves* 433

UNIT FIVE · THE HYDROSPHERE AND THE ATMOSPHERE ARE THE CHIEF FACTORS OF WEATHER

CHAPTER TWENTY-FIVE · *The Earth Possesses Characteristics Which Make Life Possible* 449
CHAPTER TWENTY-SIX · *Weather Proceeds from Atmospheric Conditions* 470

UNIT SIX · THE EARTH'S SURFACE IS CONTINUALLY CHANGING

CHAPTER TWENTY-SEVEN · *The Radial Structure of the Earth Is Inferred from Indirect Evidence* 499
CHAPTER TWENTY-EIGHT · *The Surface of the Earth Is Continually Changing* 514
CHAPTER TWENTY-NINE · *Aggrading Factors Tend to Compensate Eroding Factors* 540
CHAPTER THIRTY · *Geological Forces Have Produced Many Products of Value to Man* 569

GLOSSARY 589
INDEX 601

MAN
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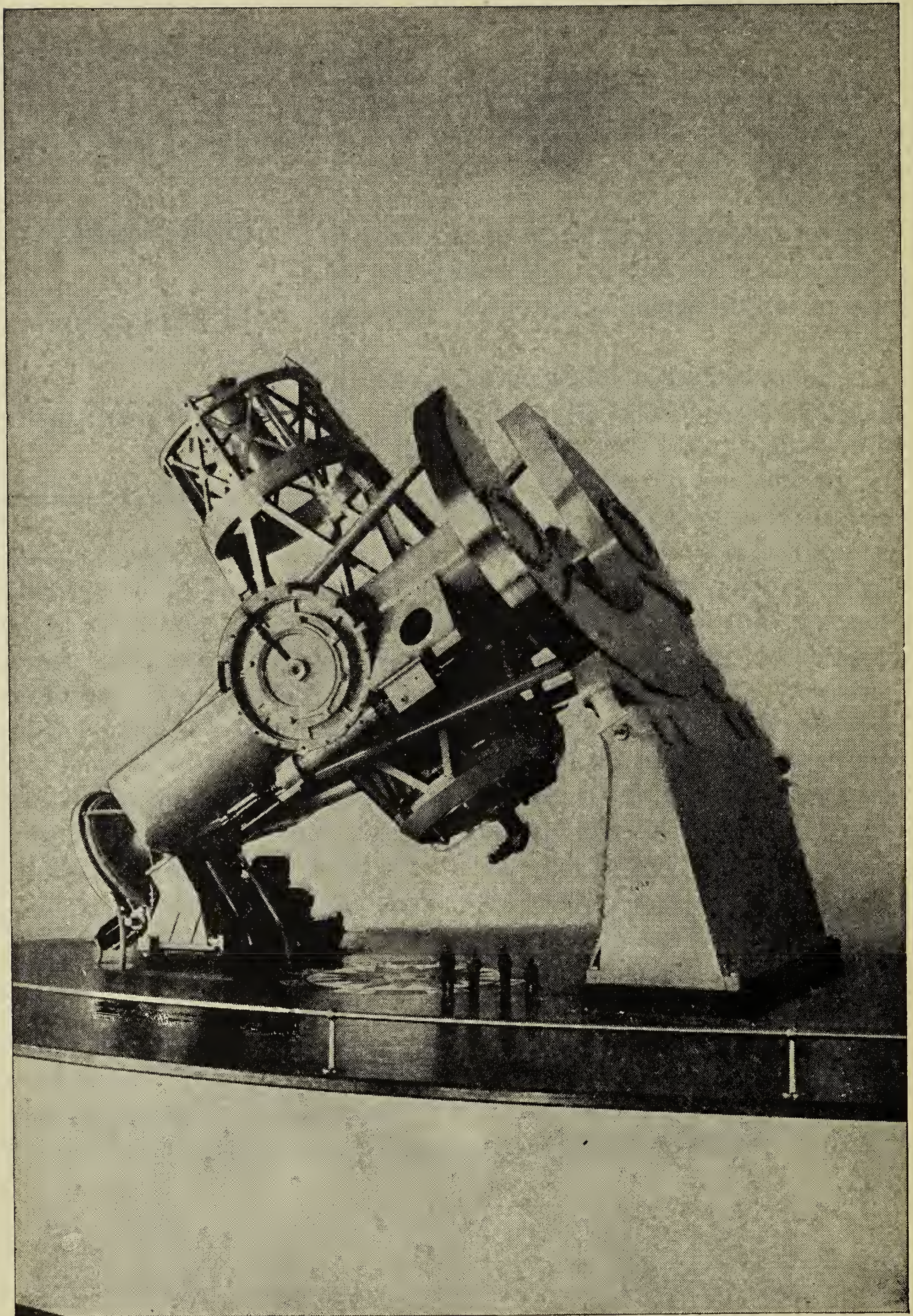


Westinghouse model, from Science Service

A $\frac{1}{10}$-scale model of the 200-inch telescope

See how small the men look in comparison with the telescope. (See page 28)

CHAPTER ONE

Ancient Man's Limited Knowledge of the Heavens Led to Erroneous Conclusions

Ancient Man Studied the Heavens Chiefly through Curiosity and a Need for Measuring Time. Apparently all ancient peoples began early to study the heavens. At the outset they were probably motivated by sheer curiosity and wonder. The spectacle of the rising and setting sun, the phases of the moon, and the starry host that greeted the eye of the shepherd, peasant, and philosopher alike, all must have aroused their admiration and interest.

But curiosity, as a source of interest in the heavens, was supplemented very early by another motive. The ancients were struck by the periodicity which they observed in the movements of the celestial bodies: the sun's apparent daily journey across the sky from east to west, its seeming regular movement north and south across the equator, the rhythmic recurrence of the moon's phases, the periodic reappearance of Venus as evening star or morning star, and the succession of both lunar and solar eclipses. These and many other celestial movements challenged their attention. Moreover, these observations finally offered a suggestion of great practical value. The early ancients had no way to tell time and to record events in chronological order. The regular rhythmic movement, either real or apparent, of the sun, moon, and stars offered a clock by which this might be done. For the most part, however, the ideas of the ancients regarding the heavens were a strange admixture of fact, superstition, and error.

A Few Greek Scholars Reached Some Remarkable Astronomical Conclusions. Among the Greeks also the popular conception of the cosmos was heavily burdened with myth and superstition. In fact, as with most peoples of that far-off age, it is sometimes difficult to determine how one should classify their statements—whether as theogony, which is a genealogical account of the gods, or as cosmogony, which treats of the origin of space and the celestial bodies which it contains.

Since classical Greece could claim many brilliant minds, there were naturally divergences of opinion and great confusion of truth and speculation. By some philosophers the earth was considered as a special body in the center of the universe and the stars as fiery bodies nourished by vapor. Some accorded the sun the chief place in the heavens but relegated the stars to the lowest estate.

Although the ancient Greeks had much of myth and fancy incorporated in their ideas of the heavens, nevertheless the honors for being the true founders of the science of astronomy must go pre-eminently to them. What was discovered about the heavens by certain illustrious Greeks of the Periclean Age, as well as of the following period, fills us with astonishment and arouses our most ardent admiration.

Hamilton Watch Company

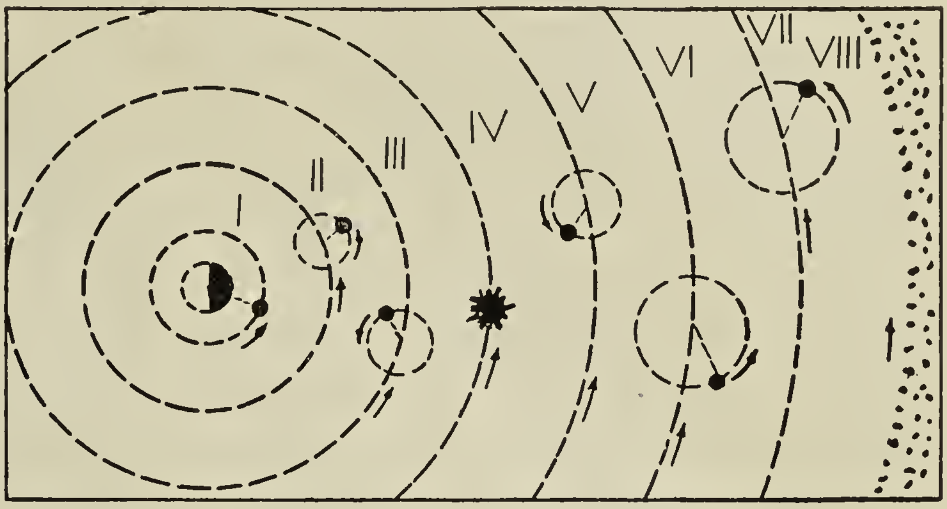
The Aztec calendar stone

A record, written in Aztec characters, of the earth's revolution about the sun

Those Greek scholars recognized that the passage of the moon between the earth and the sun causes the solar eclipse, and they recognized that the shadow of the earth produces the lunar eclipse. For the older idea of a revolving dome which carried the attached stars with it across the sky, Heraclides substituted the conception that the earth itself rotates and that this alone makes the motion of the stars apparent. Democritus believed the Milky Way to be but a vast aggregation of stars so far away as to seem indistinct and misty. It took twenty centuries and the telescope to verify this theory. Eratosthenes measured the inclination of the earth with the plane of its orbit and set it at 23° 51′, a figure now known to have been but 6′ in excess of the truth.

Many learned Greeks believed the earth to be round long before the day of Columbus or the historic voyage of Magellan. They arrived at this conclusion largely as a result of their observations made while journeying down to Egypt to visit the famed library at Alexandria. In making this passage the travelers noted that stars invisible in Greece arose above the southern horizon and stood far up in the sky by the time they reached their destination in Egypt. These Greeks reasoned that this appearance and seeming movement of the stars could have taken place only as a result of having traveled over a curved surface.

Of all the Greeks, however, whose ideas of the heavens illuminate the pages of early astronomy, Aristarchus stands pre-eminent. He hit upon the theory that the earth and other planets moved around the sun. For, he argued after a series of calculations, the sun is at least seven times greater than the earth, and how could the greater body turn about the smaller? Aristarchus, however, suffered the fate of many men whose ideas have been ahead of their time. No one accepted his theory, and it took two thousand years to prove that he was right. His fellow citizens of Samos accused him of impiety, for they believed the stars to be a celestial host of lesser divinities.



The epicycles of Hipparchus, showing the earth at the center of the universe

I, the moon; II, Venus; III, Mars; IV, the sun; V, Jupiter; VI, Saturn; VII, Uranus; VIII, the stars in the outer dome of the heavens[1]

Interpretation of the Heavens Has Been Greatly Confused by Belief in Astrology. In view of the derivation of the word *astrology* (Greek *astron*, "star," + *logos*, "discourse") astrology should be in perfectly good repute. At the outset it did enjoy a certain reputation; but from the beginning it had a dual meaning which in the end caused its downfall. Astrology, even through the Middle Ages, included certain facts which man had discovered regarding the heavens. But there was another side to it, which was pure superstition. That was the belief that the heavenly bodies were either divinities themselves or were under the immediate direction of these divinities, and that the movements and relations of these bodies controlled the fortunes and destinies of man.

This theory, like many other errors, grew up easily. It began with indisputable facts of life. The ancients observed that good crop yields depended upon the sun; that rains fell from the sky to refresh the earth; and that when the moon was full it illuminated the earth with a benign light. Sometimes, however, the heavens seemed to be in a tempestuous mood. Gleaming bolts of lightning flashed from the clouds, followed by reverberations that shook the earth. Not infrequently, too, these fiery blasts were fraught with consequences tragic to both man and beast. On occasion the winds raged with a force that beat the ocean into mountains, demolished buildings, and flattened the grain in the fields. Almost annually floods poured down the river valleys, often leaving devastation in their paths. In coping with these forces man was just as helpless then as he is today. Doubtless by pure chance, at first, a near coincidence of events was noticed. The heavenly bodies presented a certain conjunction in their movements or some unusual appearance. Immediately afterward, some event took place which was either fortunate or unfortunate for man. It might have been the success of an army in battle or a failure of the crops. Straightway was made the agelong error of connecting two such events as cause and effect, just because they happened to follow each other in close succession—and astrology, as superstition, was born.

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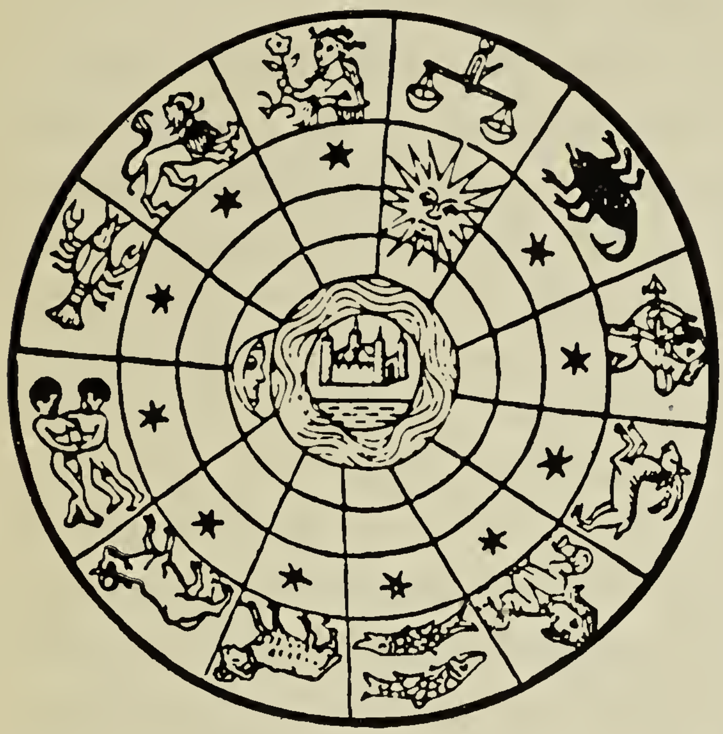
[1] From *The Great Astronomers*, by Henry Smith Williams. By permission of Simon and Schuster.

Little wonder, then, that forces now recognized as perfectly natural should gradually assume supernatural proportions, and that the superstitious aspect of astrology should come to be the dominant one! People of that remote time, just as most of us today, were less interested in the pursuit of pure astronomy than they were in dependable ways of predicting the future. So astrology grew and expanded. Arrhenius tells us that "the planets were regarded as gods and credited with more freedom than the stars." Their appearance came to be interpreted as a "happy or unhappy foreboding for life and death, for inheritances, and for human projects." The sun and moon were also included among these divinities, and their movements were regarded as important in influencing events upon the earth.

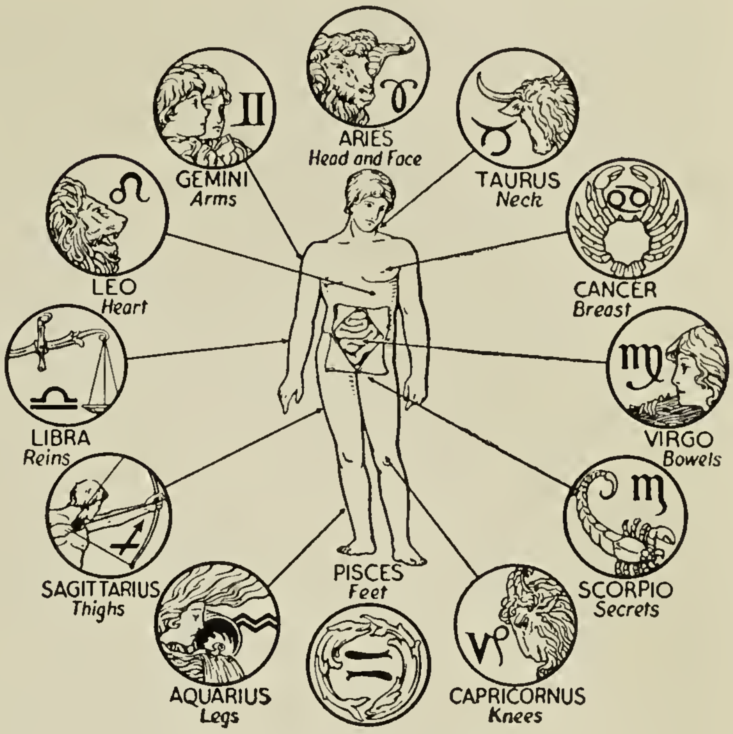
At first these omens were used only in connection with public enterprise and the person of the king. Naturally enough, however, under the interest and encouragement of the priesthood, the system grew both in extent and in application. It came eventually to include all astronomical bodies. The myriad movements of the celestial bodies, eclipses, appearances of comets, changes of the moon, storms, thunder and lightning, the movement of clouds, the direction of winds, and at length all events in the heavens and many on the earth came to be looked upon as omens. Moreover, if these events were significant with respect to the person of the king, why not for the private citizen as well? So they were extended to include him. The position of the stars and planets at the time of one's birth or at the time of one's conception—there were differences of opinion on this point—was considered to be particularly portentous.

But the system was becoming too involved for the ordinary person to interpret. Consequently the priests gradually assumed positions of greater prominence and influence. They posed as having the ability to prepare *horoscopes* for the people. These horoscopes predicted the fortunes of a person and propitious times for his enterprises as determined by the movements of the celestial bodies. As Riley says of these priests,

. . . they claimed that the heavenly bodies by their movements offered to men much secret information, an eclipse presaging a disaster to the royal army, a comet the coming of a plague. Naturally the priests kept such secrets to themselves, but they were willing to sell them for a consideration. If a king were going to war, they would tell him that the stars in their courses would fight for him, or, descending in the social scale, would cast a horoscope for a farmer in order to tell him the right time to plant his crops.[1]



A concept of the earth as the center of the universe, surrounded by the zodiac and the guiding stars



Signs of the zodiac

Astrology seems to have flourished among the Babylonians and to have issued from Babylon as a center to influence the ideas and practices of practically all ancient and medieval peoples. At length even plants and animals came to be regarded as being under the influence of heavenly bodies. As the system expanded, the fate of the individual became connected with the signs of the zodiac. The zodiac, the reader will recall, was an imaginary belt around the sky, roughly described by one's line of vision through the sun as the earth made one complete revolution. It included twelve constellations: *Aries*, the ram; *Taurus*, the bull; *Gemini*, the twins; and so on to *Pisces*, the fishes. Moreover, the zodiac was regarded as a sort of prototype or model of the human body, so that each of the principal parts of the body corresponded to one of the twelve signs of the zodiac. In addition, each of the twelve approximately equal periods of the year, beginning on the eighteenth of one January and running to the eighteenth of the next January, was conceived of as being ruled by one of these constellations. Consequently if an ordeal connected with the body was to take place, it should be undergone when the sign was right for that particular part of the physical organism.

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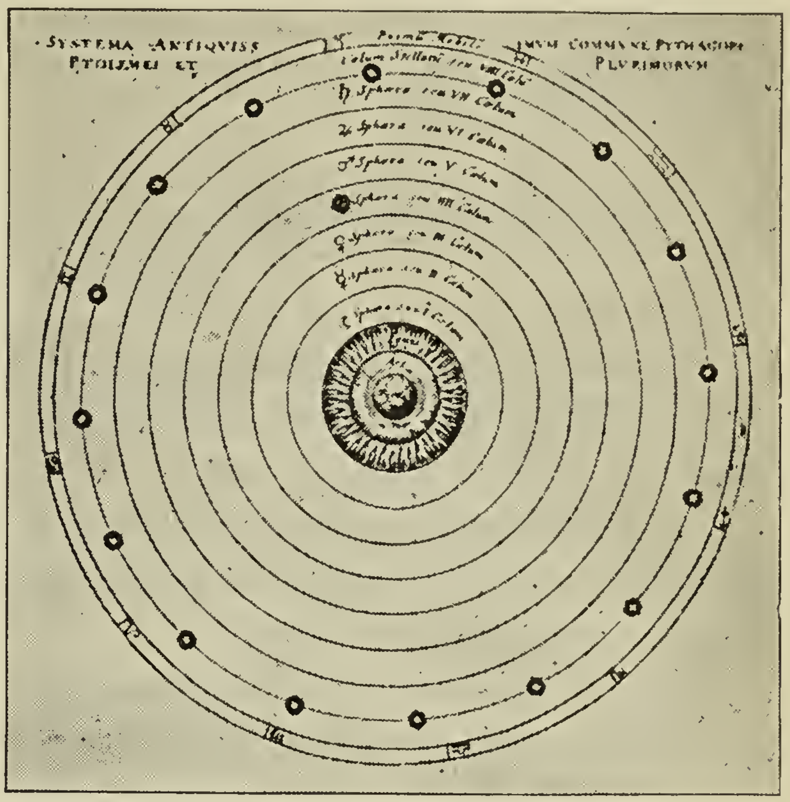
[1] Woodbridge Riley, *From Myth to Reason*, p. 24. D. Appleton-Century Company, Inc., 1926.

The growth and development of science has dealt a staggering blow to astrology. As Sir Richard Gregory, former president of the British Royal Society, has so aptly said, "no convincing evidence has yet been submitted to the court of science to establish any direct connection" between the moon and the weather and the planets and "human life on the earth in the past, present, or future." Nevertheless, belief in astrology's superstitions has persisted to a surprising degree even to this day. People who plant their potatoes in the dark of the moon to ensure a yield, or slaughter their meat animals at a certain time to prevent undue shrinkage when the meat is cooked, are following the teachings of astrology. Not long ago the writer heard a farmer remark that the next week would be a good time to dehorn a calf which he owned because the zodiacal sign would then be in the head and this would prevent excessive bleeding. Many current newspapers carry syndicated horoscopes for each day of the year. The horoscopes, in rather vague terms, purport to foretell the personality traits of a person born under particular astronomical conditions and to predict in an equally vague manner something of the environmental forces that will influence his life.

A recent check of the newsstands in a Western town of 14,000 population showed nine different astrological periodicals in the magazine racks, with the dealers reporting a good volume of sales. One of these publications recently carried a call for ten thousand consulting astrologers, urging this vocation as a "well-paying profession, and one which offers unlimited opportunities for aiding humanity." It was also reported in November, 1941, that a Hollywood motion-picture producer was preparing to release a series of twelve films on astrology.

The Ptolemaic Theory Dominated the Thinking of Man for Centuries. In the city of Alexandria, Egypt, there lived a man by the name of Ptolemy. Little of his personal history is known, but it is fairly well established that he began his recorded observations in 127 A.D. and completed his work in 151 A.D. During these years he worked out a system of astronomy that held sway over the minds of men for a period of almost fourteen centuries. In addition he gathered up the wisdom of the ancients regarding the stars and incorporated it, together with his own observations and theories, into the most famous of all old astronomical records, the *Almagest.*

By watching the stars Ptolemy arrived at the conclusion that the earth is the center of the universe. He believed it to be massive and to have a curved surface, for which he adduced many proofs current today. He assumed that it was a stationary sphere. According to his argument this assumption led to the startling consequence that the earth could have no supports. He believed it to be simply balanced in space. Since it was the center of the universe, he reasoned that any direction taken from the earth out toward the stars must be upward. Since the fixed stars retain the same spatial relation to one another year after year, and apparently revolve about the earth, Ptolemy concluded that they must in some way be attached to a vast sphere which rotated once every twenty-four hours.



The Ptolemaic concept of the universe

The earth is the center, surrounded by the spheres of the moon, Venus, Mars, the sun, Jupiter, Saturn, the stars, and the heavens

To explain this apparent daily revolution of the stars, he considered the possibility that the earth rotated, instead of the supposed dome, but discarded the idea. He could see no reason, if the earth did turn, why the atmosphere should move with it. Consequently it appeared to him that if the earth rotated at a speed necessary to make its complete turn in twenty-four hours, it would develop a very high wind. Should the earth rotate, he argued, this air blast would sweep people off their feet, and birds rising into the air would be carried back much faster than they could fly forward.

Ptolemy explained the wandering movement of the planets among the stars by a further assumption. He believed each planet to move in an independent circle of its own called an epicycle, which was set between the earth and the major celestial sphere which he had postulated.

Although Ptolemy's system contained a fundamental error, in that it considered the earth to be the center of the universe, yet, considering his time, it was really a very great piece of work. It has been said to have been far ahead of anything brought forth previously as to the structure of the universe. It is small wonder, in view of the relative mental lethargy of the Middle Ages, that its principles should have been disseminated, apparently with little question, for a period of almost fourteen hundred years. Finally, another great mind appeared whose theories completely overthrew the Ptolemaic system and set men off on the right track in their pursuit of a knowledge of the heavens. The mind was that of Copernicus, and the ideas of Copernicus concerning the solar system may be said to have introduced the period of modern astronomy.

Questions for Study

1. How did the ancients arrive at their conclusions about natural phenomena?
2. Contrast the method of investigation used by the ancients with the methods which are used by scientists today.
3. What scientific attitudes were disregarded by the Babylonians, Greeks, and Egyptians when they imputed divine characteristics to celestial bodies, such as the planets, moon, sun, and stars?
4. What are some common present-day superstitions?
5. When the ancients attributed personal and national success or disaster which occurred immediately after some conjunction in the movements of the heavenly bodies to the supernatural influence of those bodies, what scientific attitude were they violating?
6. When people speak of the natural and the supernatural what distinction do they make?
7. What is your conception of astrology?
8. Compare the motives which led the ancients to study the heavenly bodies with those which impel the astronomer to investigate today.
9. What current beliefs have you noted among laymen which, like that of the farmer who wished to dehorn his calf in a certain "sign," are survivals of astrology?
10. How is the gradual displacing of superstition affecting man's points of view and behavior?
11. What would be your reaction to the popular habit of mind in Ptolemy's time of accepting his pronouncements regarding many questions of the day, unrelated to astronomy and geometry, as being final just because he was an eminent astronomer and geometrician?
12. In your experience as an individual have you noted any persons who were inclined to make the same error that the people of Ptolemy's time did regarding his opinion of matters outside the fields of astronomy and geometry?
13. How would you explain the large sale of astrological periodicals and other literature of this kind today?
14. Are you aware of any superstitions that influence your own behavior? If so, why do you hold them?

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CHAPTER TWO

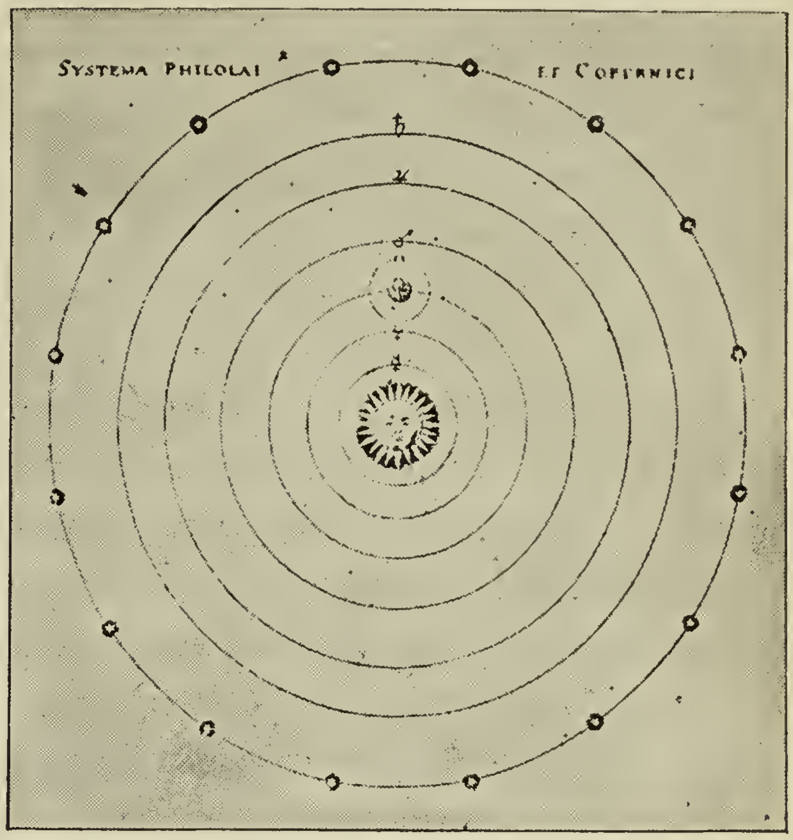
The Study of the Heavens Has Been Advanced by the Application of the Scientific Method

Rise of the Scientific Method. Owing to influences which became operative during the Renaissance, the Aristotelian plan of thinking came to be challenged. Among other things, commerce was beginning to thrive, universities were rising, a national consciousness was emerging, and the spirit of inquiry was incipient among scholars. The result was a critical attitude that refused to accept a thing as true just because it carried the label of authority. When a postulate was set forth, the scholars of the Renaissance demanded to know what observable facts supported it. If no evidence could be produced, the postulate was rejected. When this attitude became pronounced, the dawn of science and of scientific discovery was upon the horizon—an advance which has revolutionized man's thinking and has brought forth a veritable flood of dependable truth. This new critical method of inquiry is without doubt the supreme intellectual contribution of the scientific age.

The scientific method in its fully developed form is in many cases not simple and easy of application, although it is much more so than the complicated procedures of Aristotelian logic. For our purpose, we shall attempt to give only a general view of the scientific method of attack on problems in order that the reader may appreciate the discoveries and achievements of science that are to follow.

The scientifically inclined mind is an inquisitive one. Its possessor is curious to know about the universe around him, and for this reason is continually encountering problems to be solved: problems about the stars, rocks, plants, animals, other people, his own body and mind. But instead of philosophizing about them from the ease of an armchair, or gathering a few facts and then speculating widely, as Aristotle and the medieval scholars did, the true scientist gathers a great number of pertinent facts. On the basis of these facts he gives a tentative, or provisional, answer which he calls a hypothesis. He will not accept this tentative answer as a final one, however, until it has been verified. The answer must be tested and proved. This is the chief difference between a speculative conclusion and a scientific one. In his verification the scientific worker may make more observations, collect more data, conduct new experiments, repeat those he has already made and thus subject his hypothesis to actual trial. If it stands up under all these further tests, the scientist then accepts it as a law of nature valid in the realm in which the tests were made.

The scientific method and its discoveries did not come into full prominence until the beginning of the seventeenth century; but its roots took hold more than a hundred years earlier. In fact, one writer declares that "Copernicus stands forth as the first modern scientific thinker" and through his work modern astronomy had its inception.



The Copernican concept of the universe

The sun is the center. Revolving about the sun, in order, are Mercury, Venus, Earth, Mars, Jupiter, and Saturn. Beyond these are the star-studded heavens

The Copernican Theory Supplanted the Ptolemaic Conception. Nikolaus Copernicus was born at Toruń, in Poland, in 1473. He had the advantage of the best schools in his country and studied under skilled teachers of medicine, mathematics, and astronomy. At the age of twenty-seven, because of his unusual ability, he was made professor of mathematics at Rome. One of his chief duties in this connection was to expound the teachings of the still dominant *Almagest.* In 1502 Copernicus returned to Poland and entered a religious order.

From his study of the stars he arrived at the conclusion that they and other celestial bodies must be vast objects at tremendous distances from the earth. It did not seem plausible to him that the stars could be attached to a huge revolving dome, as Ptolemy had taught. The more he studied, the more he became convinced that the teachings of Ptolemy involved a fundamental error. At length, in 1507, he began the preparation of one of the most famous books in the whole history of astronomy, *De Revolutionibus Orbium Caelestium,* which means "Concerning the Revolutions of the Heavenly Bodies."

As a result of his study he arrived at the belief that the apparent movement of the stars and other heavenly bodies could be much better explained by the assumption that the earth itself rotated instead of a surrounding, star-studded celestial dome. To support his point he argued that the apparent revolving movement of the celestial bodies was much like the illusion that a person in a ship experiences as it sails past objects on the shore: the objects seem to be moving rather than the ship. Moreover, Copernicus became convinced, on the basis of careful observation, that Ptolemy's assertion that the rotation of the earth would produce continuous, very high winds was wholly preposterous. For, said he, if the earth turns, the air will drag against its surface; and the rubbing effect will soon cause the surrounding air to turn with it.

The active mind of Copernicus, moreover, did not stop with this intellectual achievement. By a strict train of reasoning he became certain, as did Aristarchus sixteen hundred years before, that the sun, and not the earth, is the center of our system. He believed that the sun is stationary, and that the earth is but a planet, which, with other planets, revolves in regular periods about the sun; that the moon is but a relatively small body, or satellite, accompanying the earth and revolving about it much as the planets do about the sun.

For almost forty years Copernicus worked on his new theory of the universe. For twenty-seven years, he tells us, scarcely a day or a night passed that he did not add something to it. One would suppose that such a monumental conception, which avoided the old Ptolemaic difficulties and brought order into our understanding of the universe, would have been received with acclaim. But it was not. His grasp of great astronomical truths was far ahead of his time, and he had to suffer because of his advanced ideas.

For the seeming indignity to man, which removed him from the center of the universe, the voice of Copernicus as a public teacher was silenced. Yet night after night he worked on. He is said to have watched the movements of the heavenly bodies through holes which he had cut in the roof of the barn behind the house where he lived. The priests and university teachers were ordered to let Copernicus and his theories severely alone. Yet, persecuted as he was, he found great peace of mind in his work. As the stars moved apparently in sublime silence across the sky, he said: "They do me great honor. I am forbidden to converse with great men, but God has ordered for me a procession."

Restricted in his public utterances, Copernicus decided not to publish his beliefs but to trust his friends to pass them on by word of mouth. From this course, however, his friends finally dissuaded him, and his famous book, *De Revolutionibus Orbium Caelestium*, was written.

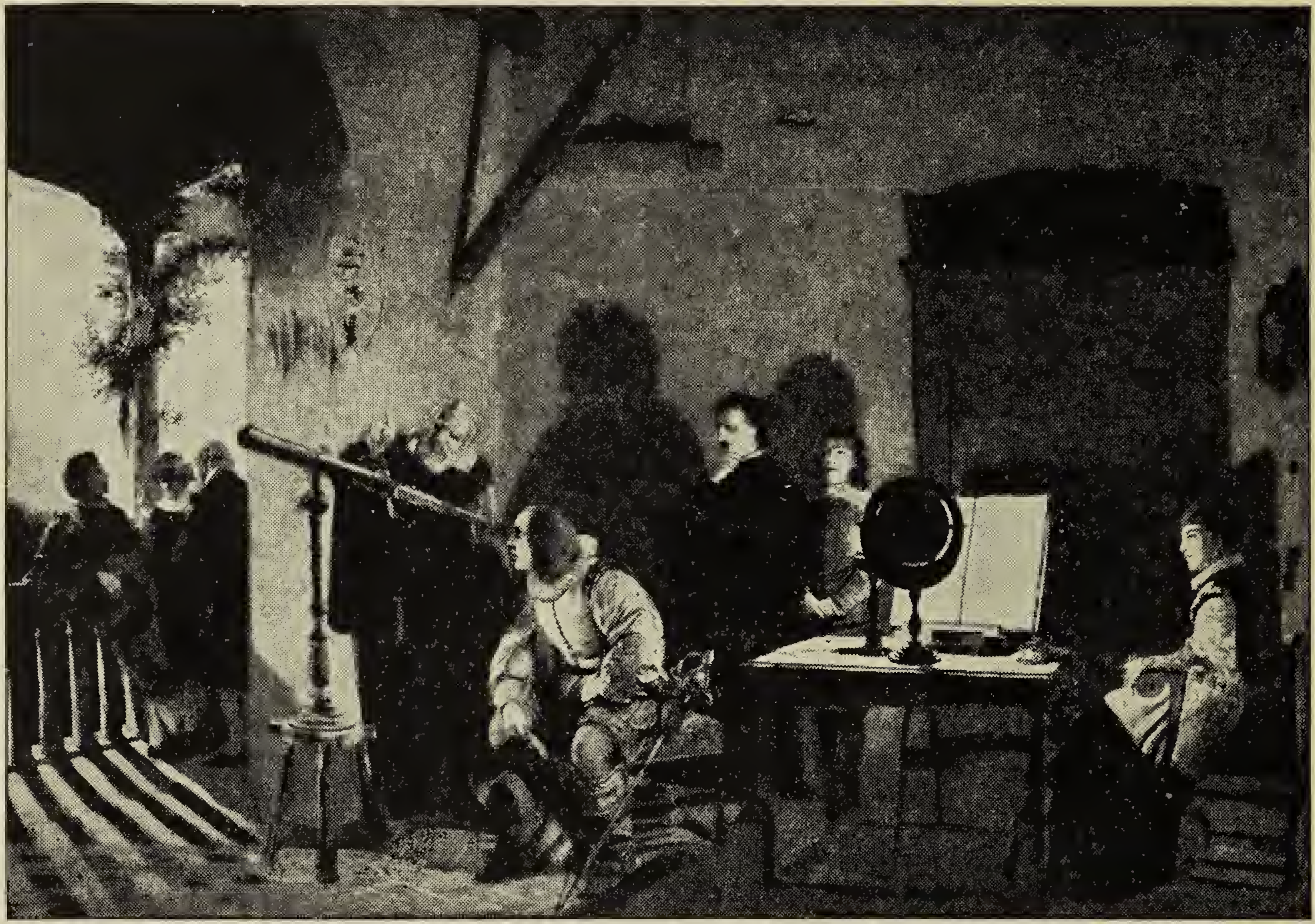
Copernicus dedicated his book to Pope Paul III. In his dedicatory letter he not only makes clear his object in writing the book, but sets forth the steps by which he reasoned to his conclusion. It is such a clear presentation of the new scientific method of thinking which was fully ushered in about a century after Copernicus's death that every student of science should be acquainted with it. Said he:

> When I for a long time thought upon the uncertainty of the traditional mathematical doctrine concerning the paths of the heavenly bodies, it seemed to me very lamentable that still no more correct theory had been advanced by philosophers for the movements in the universe which the best and most perfect architect had made for us, while they have so accurately investigated many relatively unimportant things. Therefore, I took the pains to read through the writings of all the philosophers that I could get together in order to find out if some one of them had not stated the opinion that the movements of the heavenly bodies might be other than the professional mathematicians had asserted. And I did find in reality first in Cicero that Nicetas had thought that the earth moves. Afterward I read in Plutarch that some others had also been of this opinion. . . .
>
> When I had received this suggestion, I began myself also to meditate upon a motion of the earth. And although this theory might seem nonsensical, yet because I knew that to others before me the liberty had been allowed to suppose all sorts of circles in order to explain the phenomena in the heavens, so it would be permitted me also to try whether on the theory of the motion of the earth more satisfactory explanations than heretofore might not be found for the movement of the heavenly bodies.
>
> After I had assumed the motions which I assign to the earth in the following work, I found, after careful investigation extending through years, that if the movements of the other planets were referred to the motion of the earth in its orbit and reckoned according to the revolution of each star, not only could their observed phenomena be logically explained, but also the succession of the stars, and their size and all their orbits, and the heavens themselves would present such a harmonious order that no single part could be changed without disarranging the others and the whole universe. In accordance with this theory, I have drawn up the plan of my work.[1]

Unfortunately Copernicus was on his deathbed when the first copy from the publisher reached him in 1543. When friends presented it to him, he aroused from his weakened stupor and is said to have pressed it to his heart with a smile. A few days later he died. Thus passed the man who had set the world right as to the nature of the earth and its relation to the rest of the universe.

Of the truth of the Copernican system, however, the world was not yet convinced. It took a telescope in the hands of Galileo, a mighty defender of Copernicus, to initiate that long chain of evidence which later completely

[1] Leopold Prowe, *Nicholaus Coppernicus*, Vol. I, Part 2, pp. 498–500. From the translation by George B. Adams, in the *Yale Review*, Vol. 1, p. 160.



Milton in the studio of Galileo

overthrew the Ptolemaic theory and established our planetary system as heliocentric.

Galileo Was an Independent Thinker Representative of the New Age. Born in 1564, twenty-one years after the death of Copernicus, Galileo began early to manifest those qualities of an inquisitive, skeptical mind characteristic of the dawning scientific age. One of his biographers has this to say of him:

> In those days the doctrines of Aristotle were regarded as the embodiment of all human wisdom in natural science as well as in everything else. It was regarded as the duty of every student to learn Aristotle off by heart, and any disposition to doubt or even to question the doctrines of the venerated teacher was regarded as intolerable presumption. But young Galileo had the audacity to think for himself about the laws of nature. He would not take any assertion of the fact on the authority of Aristotle when he had the means of questioning nature directly as to its truth or falsehood.[1]

It was this spirit of independent thought and inquiry that prompted Galileo, as a young professor at Pisa, to challenge the teaching of Aristotle regarding the law of falling bodies. The latter had asserted that the time occupied by a stone in falling depends upon its weight, and that the heavier the stone the faster it falls. Galileo contended that this position was erroneous, and that, if the resistance of the air were disregarded, bodies would fall at the same rate regardless of their relative weights. Being a true scientist he resorted to experiment to prove his point. He dropped two weights, one ten times heavier than the other, from the leaning tower of Pisa, with many of the university faculty and populace as spectators. The weights struck the ground at the same instant. Science had spoken and through the new method of attack had completely exploded a speculative fallacy taught for almost two thousand years.

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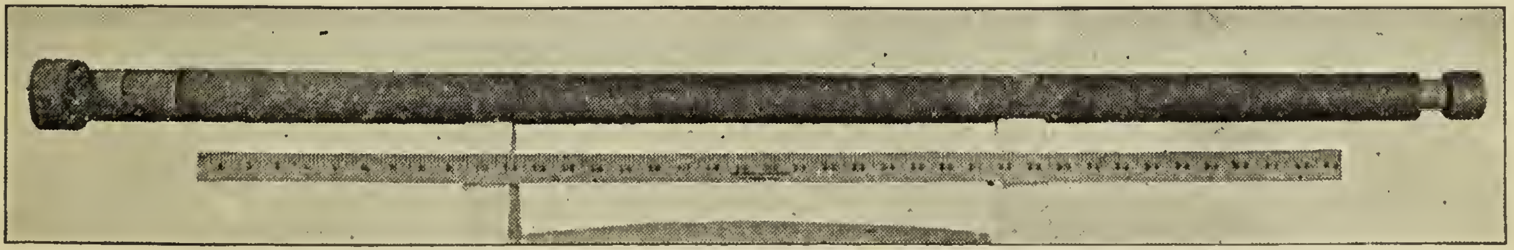
[1] Sir Robert S. Ball, *Great Astronomers*, p. 69. Isbister and Co., Ltd.

Galileo Made a Telescope and by the Use of It Greatly Extended Astronomical Knowledge. Until after the death of Copernicus astronomers had no telescopes to assist them. Their observations and notations as to the location of the heavenly bodies were made with a sort of gun-sight device set in a circle, such as the astrolabe.

Galileo, a professor at Padua, Italy, heard of the telescope. His imagination was fired immediately. He is said to have sat up nearly all that night working out the principle and devising a telescope of his own. When the instrument was completed and reported, popular interest was so great in Venice that Galileo was summoned to exhibit it to members of the senate. He tells us that "many gentlemen and senators, even the oldest, have ascended at various times the highest bell-towers in Venice to spy out ships at sea making sail for the mouth of the harbor." He declares that these ships could be sighted two hours before they came within the range of the unaided eye and that "the effect of this instrument is to show an object at a distance of say fifty miles, as if it were but five miles."

But the greatest revelations were to be made when he pointed his telescope toward the heavens. By 1610 he had perfected a telescope that magnified thirty diameters, and with this, as Professor Frank Schlesinger, of the Yale Observatory, has said, "Discovery after discovery of most startling character followed in rapid succession."



Mount Wilson Observatory

Replica of the telescope used by Galileo

Note its size as compared with the meter stick

He aimed it at Jupiter and found four of its moons moving about the planet in regular order. Up to this time no argument regarding the validity of the Copernican theory had arrested public opinion so thoroughly as this discovery. If Jupiter, men reasoned, could move through the heavens, and yet hold four moons revolving about it, it did not seem so unreasonable to believe that the sun also, which has a much greater mass, could actually hold all the planets in place about itself as they go revolving in their orbits.

But this was only one of Galileo's discoveries. Others followed. He found the surface of the moon to be a series of plains and mountains, as Anaxagoras had suggested twenty centuries before; he observed the presence of sun spots and by them detected the rotation of the sun. He saw the strange rings of Saturn; he discovered the phases of Venus, similar to those of our moon; and he ascertained that the Milky Way, in truth, is made up of myriads of distant stars, just as Democritus had asserted two thousand years before.

Under the teachings of Ptolemy great importance was ascribed to man. He dominated the earth, which, with the sun and planets revolving about it, was the center of the universe. Now if Copernicus and Galileo were right, what a fall man's pride must take! His earth, instead of being the center of things, was but a dwarf among the planets. Even Jupiter, the largest of the planets, was but a pygmy compared with the sun. This was a severe blow to man's self-esteem and, as man then supposed, wholly incompatible with his ideas of God's concern for him. Galileo had made a telescope and other telescopes followed; man's knowledge of the heavens increased. In subsequent years the tide of evidence rose, and in the end resulted in such a flood of proof that it swept the whole Ptolemaic system into oblivion and permanently established the fundamental truths of the discoveries of Copernicus and Galileo.

But to know the heavens as we know them today, man's relatively feeble eye had to be re-enforced and supplemented by many other instruments. The spectroscope had to be discovered and applied (p. 32); astronomical photography had to be employed; the thermocouple (p. 35) had to be invented; and many more auxiliary aids had to be devised and perfected. Lastly giant telescopes had to be built—instruments without which these other appliances would have been of little value.

Questions for Study

1. What scientific attitude in particular is manifested by the shift to the acceptance of the Copernican theory in place of the Ptolemaic system?

2. What is your conception of the scientific method?

3. What steps are usually formulated as representing the scientific attack upon a problem?

4. Someone has said that the scientific method is nothing more than straight thinking. What is your opinion of that statement?

5. To what extent is the scientific method of attack in solving problems applicable to the search for truth in other fields of knowledge?

6. Why did this careful method of searching for dependable truth come to be named the scientific method?

7. To what extent do most of the important problems which you have to solve involve all steps in the scientific method?

8. What scientific attitude was exhibited by Galileo in his eagerness to perfect a telescope with which he might study the heavenly bodies?

9. Are there parallels between the opposition which Galileo encountered in his search for truth and the opposition encountered by truth-seeking men and women today? Can you point out some in modern life?

10. Some students of scientific history regard Galileo as initiating the age of science rather than Copernicus. What is your opinion?

11. How does the work of Ptolemy, Copernicus, and Galileo exemplify the scientific attitude that "truth itself does not change, but man's conception of truth often does change"?

12. Can you give instances in which your opinions of principles or of people have been changed by additional information?

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CHAPTER THREE

Knowledge of the Heavens Has Been Extended through the Use of Astronomical Instruments

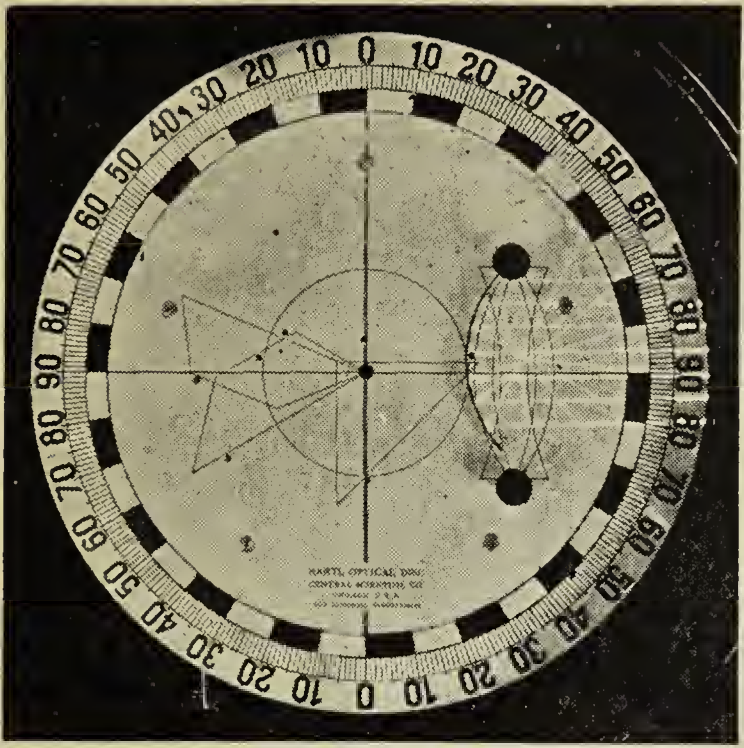
Light Has Various Properties Which Are Utilized in Astronomical Instruments. The knowledge which man has acquired of the outer worlds comes to him through the agency of light. Luminous bodies of the cosmos send out light messages in all directions.

Reflection of light by a plane surface

Two familiar properties of light are that (1) it travels in a straight line and (2) it may be reflected. Another important property of light is that it may be *refracted.* In other words, when entering obliquely into some transparent material, such as water or glass, light rays are bent. Thus, if an object be viewed through a specially shaped piece of glass, called a lens, the rays of light from the object may be bent in such a fashion as to cause the object to appear to be enlarged. Common magnifying glasses, as well as telescopes, depend upon this property of light. Different colors are bent, or refracted, different amounts. This makes it possible to separate white light into all the different colors of which it is composed. The refraction of sunlight through raindrops to form a rainbow is familiar evidence of this property.

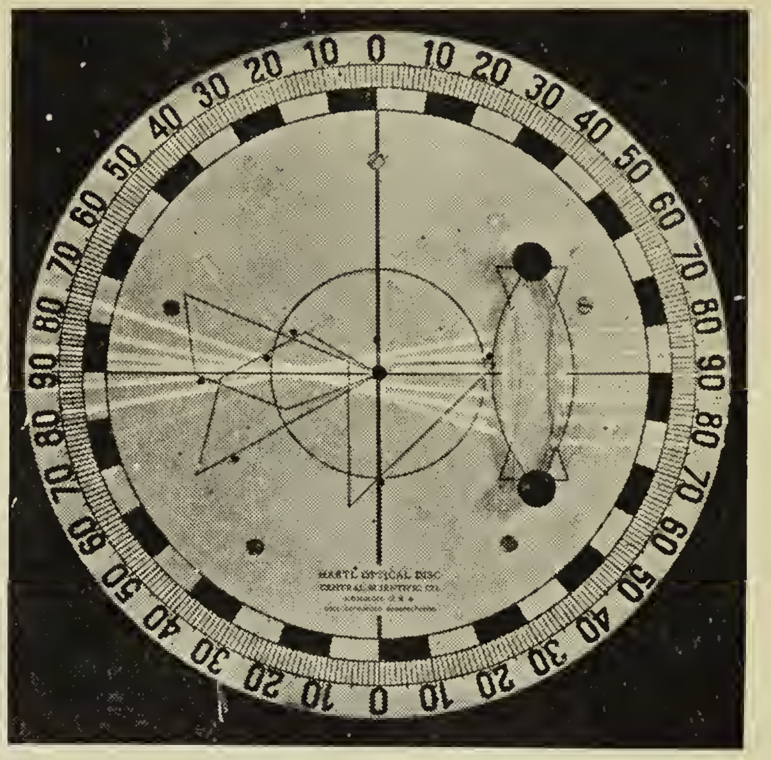
Light rays may produce chemical changes. Photography depends upon the chemical changes produced by light on the photographic plate or film. Visible light, like other forms of radiant energy (p. 267), may also be transformed into heat when the rays are absorbed by some body.

Light may be interpreted as including more than the radiant-energy wave lengths which can be seen. As a matter of fact, most astronomical studies do utilize visible wave lengths. But sometimes they do not. Photographic pictures may be taken with infrared rays which have longer wave lengths than



Reflection of light by a concave surface

See how the reflected beams are brought to a focus



Refraction of light by a double convex lens

See how the direction of the light rays is changed to produce a focus

any light which may be seen. Likewise, decided chemical effects may be produced by rays with wave lengths too short to be detected by the human eye. Everyone who has been blistered as a result of sunburn has firsthand evidence that ultraviolet waves actually reach the earth from the sun. Even such bodies as the moon and planets are studied by means of rays of light. The light originates from the incandescent sun; then, after striking these non-incandescent bodies, it is reflected to the earth.

To understand how man has been able to interpret the light received from the outer worlds, we must follow the development of the telescope. We must know something about the work of the telescope, and understand how far this mighty instrument can reach out into space to gather up the faint light rays coming from distant bodies and bring them to a focus.

Two Types of Telescopes Are Used in Astronomical Study. There are two types of telescopes employed by astronomers today. The one first invented was a refractor. Galileo's instrument was of this type. In such an instrument the image of the star is formed by refracting, or bending, the rays of light to a focus as they pass through the system of lenses arranged in the tube. The human eye is a miniature refractor. The refracting telescope is the best type of instrument for visual observations and for photography where a wide field of stars is desired. Unfortunately, however, for mechanical and scientific reasons the size of the refracting telescope that can be successfully built and used is limited. The larger the diameter of the lens, the more difficult it is to

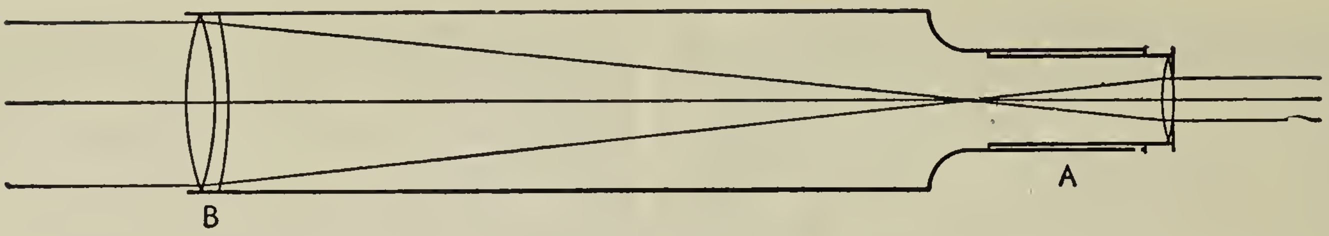


Diagram to show how the image is produced in a refracting telescope

A, eyepiece; *B*, lens

get the glass perfectly homogeneous throughout and without optical defect. Also, the thicker the lens,— and it must be made thicker as the diameter is increased,—the more the transmitted light rays are absorbed.

So Sir Isaac Newton (1642–1727) devised the reflector type of telescope to obviate the defects of the refractor. In this instrument the faint light rays from some celestial body are made to fall upon the surface of a large concave mirror at the bottom of the tube. The curved surface of the mirror converges the rays toward a focus; but in the more common type before reaching the focus the rays are thrown to one side either into an eyepiece or onto a photographic plate by a plane mirror set at an angle of 45°. In some instances the rays may be directed outside the tube even into adjacent rooms, there to be analyzed or otherwise studied as desired. If one wishes to use a reflector to look at some celestial body, the mirror has to be supplemented by lenses. These lenses, constituting the eyepiece, act like a magnifying glass for looking at the image formed by the mirror.

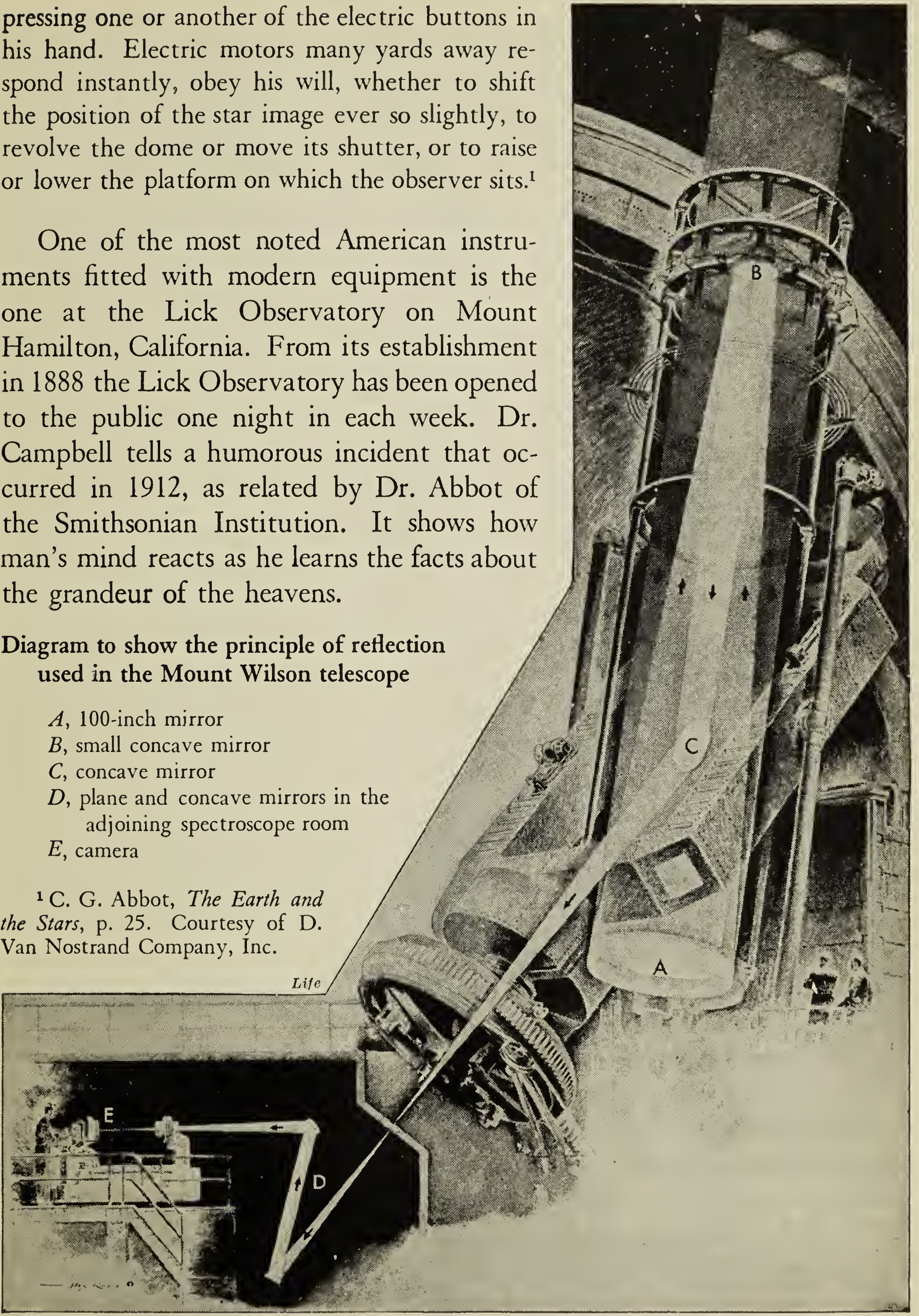
Although even with the best reflectors the intensity of the image is somewhat reduced by diffusion and absorption, nevertheless much larger mirrors can be used than lenses; and this is a great advantage. For essentially the telescope is but a huge light-gathering and light-transmitting instrument. Consequently any design that will appreciably increase this power is to be preferred for many kinds of work.

Modern Telescopes Are Superior to the One Built by Lord Rosse. Lord Rosse made the first giant reflector. He worked out the plans for the parts and, assisted by the peasants of his estate, made the instrument and mounted it in his park at Parsonstown, Ireland, in 1845. It was equipped with a seventy-two-inch mirror, and was far larger than any other telescope built up to that time. Nevertheless, compared with modern instruments, it was a crude affair. Astronomers today have devised much better reflectors. As Abbot declares:

> The modern astronomer, sitting at his post, with eye following the guiding star, has his object kept almost exactly on cross hairs by the automatic action of the self-winding clockwork, leaving him only the finest adjustments to be made, merely by

pressing one or another of the electric buttons in his hand. Electric motors many yards away respond instantly, obey his will, whether to shift the position of the star image ever so slightly, to revolve the dome or move its shutter, or to raise or lower the platform on which the observer sits.[1]

One of the most noted American instruments fitted with modern equipment is the one at the Lick Observatory on Mount Hamilton, California. From its establishment in 1888 the Lick Observatory has been opened to the public one night in each week. Dr. Campbell tells a humorous incident that occurred in 1912, as related by Dr. Abbot of the Smithsonian Institution. It shows how man's mind reacts as he learns the facts about the grandeur of the heavens.



Life

Diagram to show the principle of reflection used in the Mount Wilson telescope

A, 100-inch mirror
B, small concave mirror
C, concave mirror
D, plane and concave mirrors in the adjoining spectroscope room
E, camera

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[1] C. G. Abbot, *The Earth and the Stars*, p. 25. Courtesy of D. Van Nostrand Company, Inc.

One of the visitors upon descending from the observing chair, much interested, questioned the astronomer: "Did you say those stars are all suns?" "Yes, sir." "Did you say that those stars are really larger than our sun on the average?" "Yes, sir." "Can you give me an idea of how large our sun is?" "Well, if it were a hollow shell, of its present size, you could pour more than a million earths into it, and there would still be much unoccupied space between the earth balls." "You say there are possibly or probably planets revolving around many of the cluster stars?" "Yes, sir." "And many of those planets may be inhabited?" "Yes, sir." "Well, then I think it does not matter very much whether Roosevelt or Taft is nominated next week at the Chicago convention."[1]

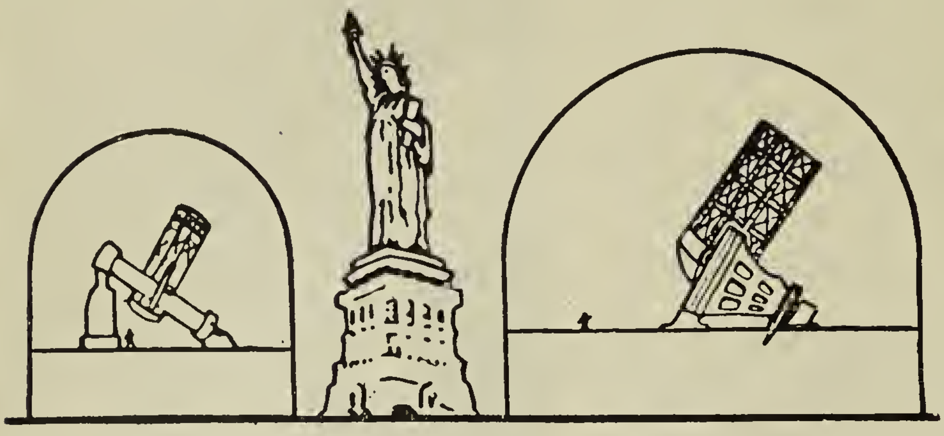

Diagram to show the relative sizes of the Mount Wilson telescope (left), the Statue of Liberty, and the Mount Palomar telescope

The Mount Wilson Observatory Contains the Most Noted Telescope in the World. The most wonderful telescope in the world sits high up on Mount Wilson, about five thousand feet above Pasadena, California. It is of the reflector type and has a mirror a hundred inches in diameter. The tube and mountings are housed in a revolving dome more than a hundred feet high, and it required seven years to assemble the parts and put them together.

The tube is mounted on great hollow cylinders resting in a bath of mercury, so that, despite its enormous weight, it can be easily and quickly adjusted to take any position desired. When the instrument has been focused on a star or other celestial object, a clocklike driving mechanism is set going. As the earth rotates, the huge tube is moved in the opposite direction at the same rate and thus kept centered on the star.

This mammoth telescope gathers in 260,000 times as much light as the human eye and catches the faint glimmer of stars 150,000,000 to 200,000,000 light-years away. A light-year is the distance light can travel in one year, going at about 186,000 miles per second, a distance equal to approximately seven times around the earth. It is equal to a distance of approximately six trillion miles. So dim are the rays that come from these remote stars that their presence is known only by the tiny light spots which they produce on a sensitive photographic plate. So reduced is the light from these far-distant

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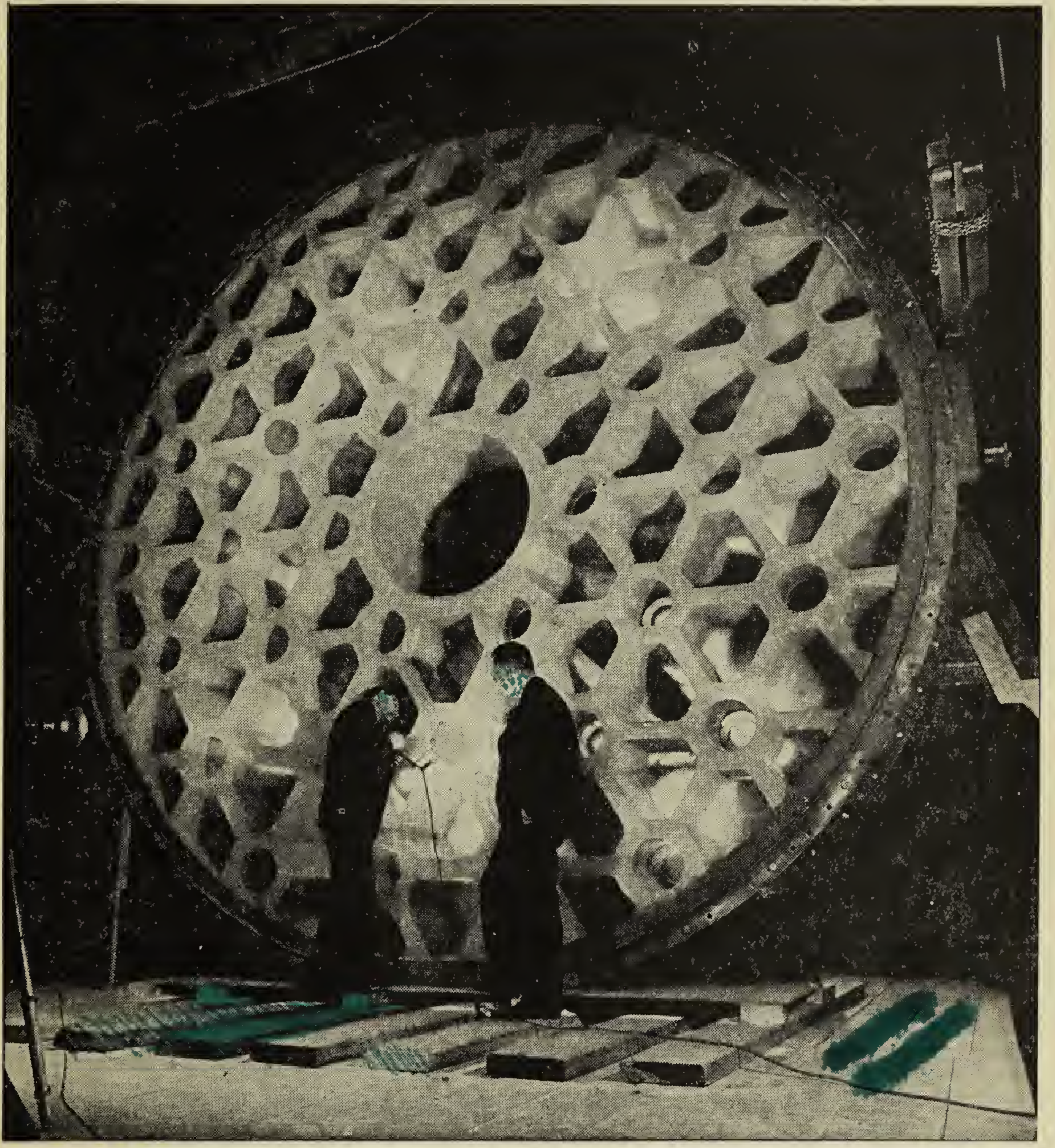
[1] C. G. Abbot, *The Earth and the Stars*, p. 27. Courtesy of D. Van Nostrand Company, Inc.



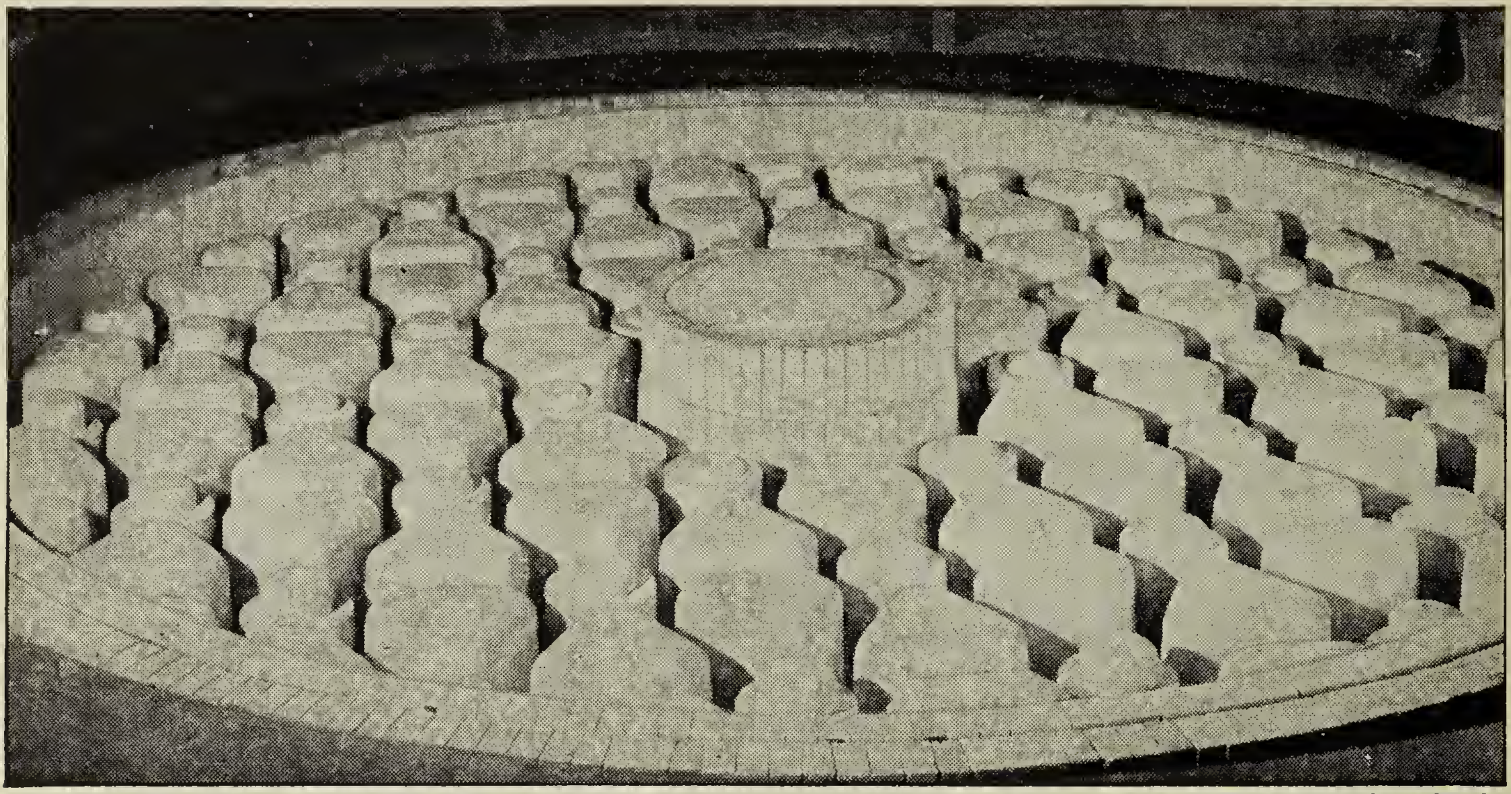
Corning Glass Works

The 200-inch mirror being examined with the polariscope to detect cracks

heavenly bodies that the plate has to be exposed for hours at a time to catch the light at all. Sometimes the exposure has to extend over two or three nights.

Man's unaided eye, viewing the sky from a single position, can see about 2000 stars on a clear night; but this giant hundred-inch reflector brings into visual and photographic view from 500,000,000 to 1,000,000,000 stars.

The Mount Palomar Telescope Is Now under Construction. Wonderful and massive as the Mount Wilson telescope is, it will be far surpassed by the great two-hundred-inch reflector now being built. The huge glass disk which



Corning Glass Works

The mold into which the hot glass was poured to form the 200-inch mirror

is to form the mirror for this great telescope was poured at the Corning Glass Works, of Pyrex fame, at Corning, New York, December 2, 1934. In the center there is a large circular hole which, as one writer has said, makes the mirror look like a huge slice of "canned pineapple." After the hot, liquid glass was set, and the temperature was reduced to 500° or 600° C, the whole mold containing the disk was moved to the annealing oven, where it was permitted to cool at the rate of only 1° to 2° a day. Cracks and other undesirable effects were thus avoided. The cooling alone required about ten months.

The mirror is to be mounted at the lower end of a sixty-foot tube, and the whole will be housed in a massive revolving dome operated by electric motors. The tube and mounting mechanism will stand about as tall as a six-story building and will weigh approximately as much as three big locomotives. The 200,000-pound tube is to be mounted in a huge yokelike mechanism whose bearings will move with almost watchlike smoothness. So delicately balanced will the tube mounting be that it will require only $1\frac{1}{2}$ horsepower to operate it.

This Goliath of instruments will gather in one million times as much light as the human eye. Since the area of the two-hundred-inch telescope is four times that of the Mount Wilson telescope, its light-gathering power will be four times as great. The range of the Mount Wilson mirror is a sphere with a radius of 150,000,000 to 200,000,000 light-years.[1] The new two-hundred-inch mirror will be able to penetrate out into the heavens three times as far and will

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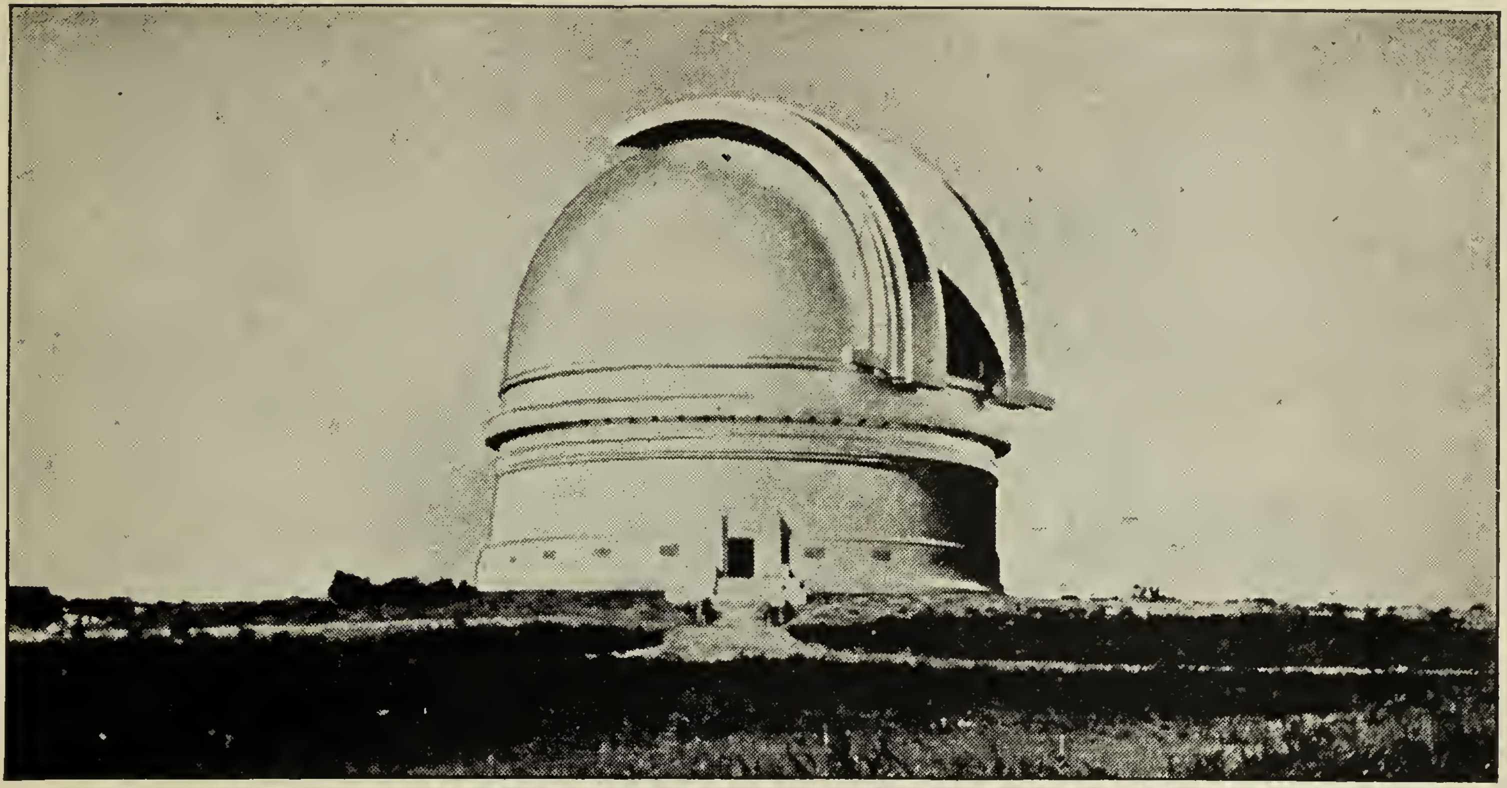
[1] Hubble has recently reported results obtained from the study of an extragalactic nebula estimated to be 500,000,000 light-years away.



California Institute of Technology

The dome that is to house the new 200-inch telescope at Mount Palomar—137 feet in diameter and 138 feet high

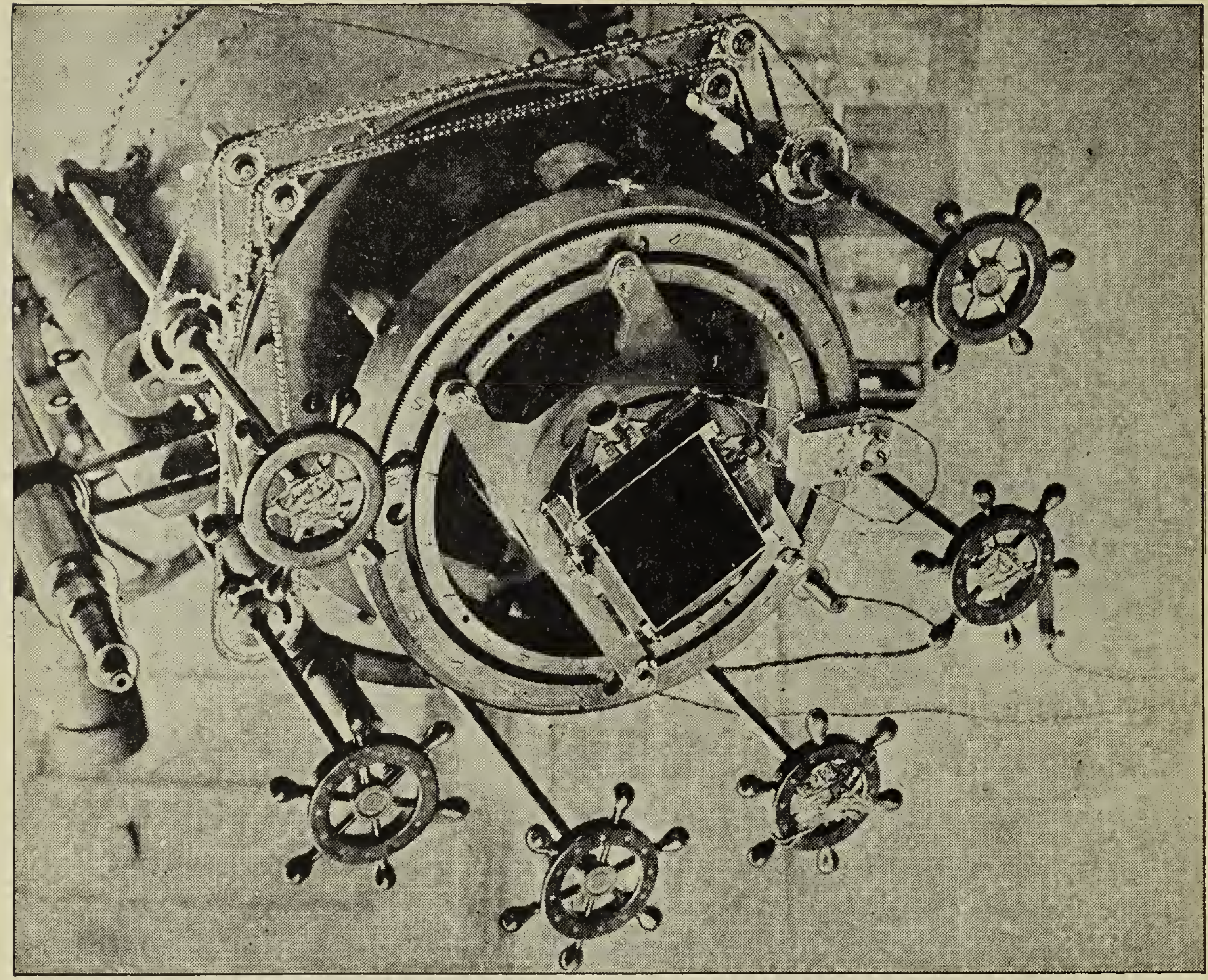
By permission of the California Institute of Technology

thus open up a sphere for astronomical investigation whose volume will be twenty-seven times that of the sphere with which we are now acquainted.

This telescope is expected to add some hundreds of millions of stars to the number now estimated. Far out beyond our system of stars, the one-hundred-inch instrument brings into photographic view a million or so great nebular bodies, of which we shall learn later. The two-hundred-inch mirror is expected to increase this number greatly. Of these distant nebular bodies present telescopes enable us to study but four or five as thoroughly as we should like. The new one, it is believed, will reach those that are 400,000,000 or 500,000,000 light-years away and enable astronomers to study more carefully twenty-five or thirty of the nearest ones.

The site selected for the erection of this great observatory is Mount Palomar, about forty-five miles northeast of San Diego, California. The flat-topped summit of this mountain is 6126 feet above sea level. Tests showed that here the atmosphere has exceptional "seeing qualities," and is free from the troublesome electric lights of Los Angeles, which often interfere with photography on Mt. Wilson.

The great observatory will doubtless become a veritable Mecca for astronomers from all over the world. One can well imagine the enthusiasm with which scientists are going about the final work on the project. One can also picture the thrill that astronomers will feel when they are able to make their first observations through the colossal telescope.

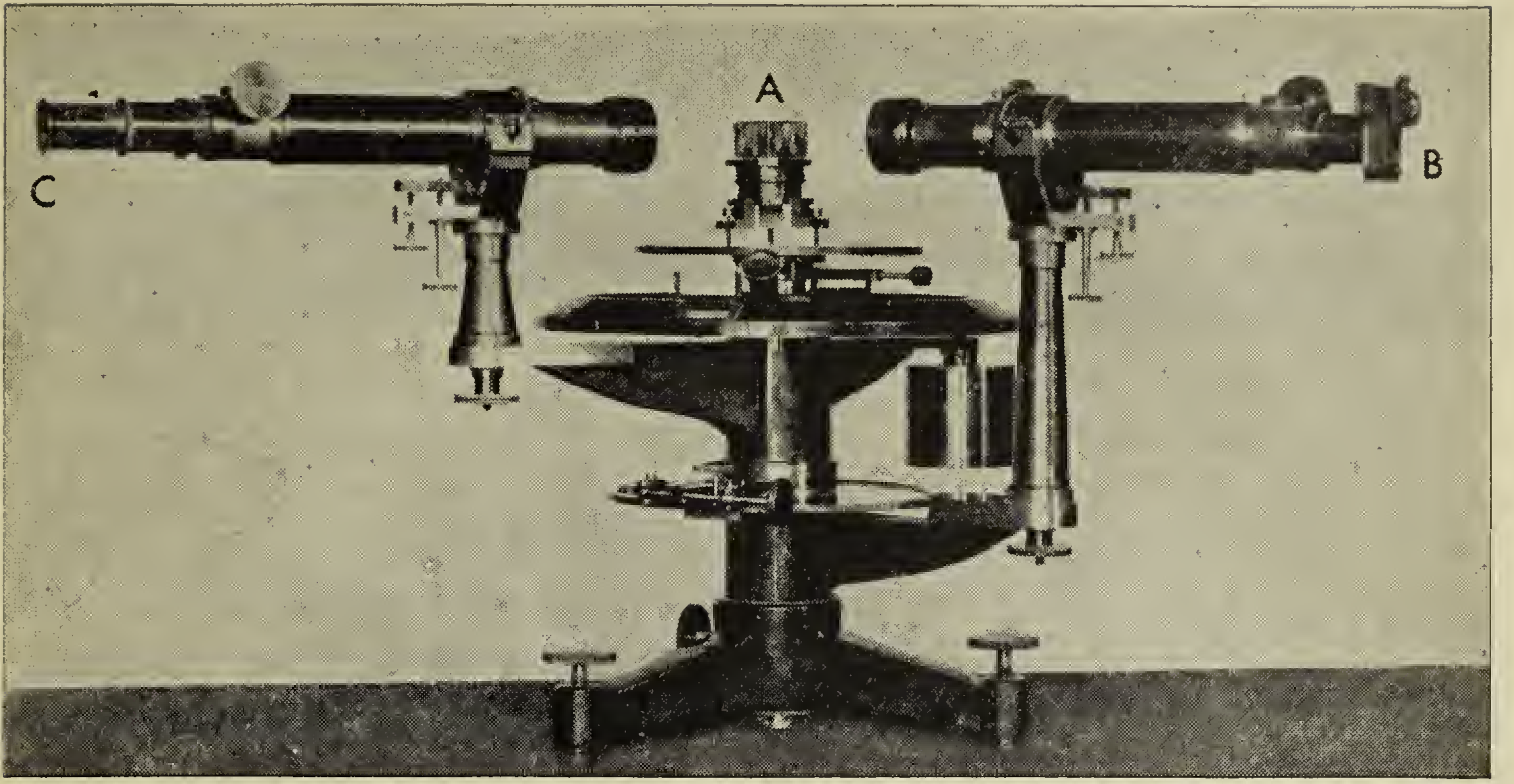


Yerkes Observatory

Double-slide plate holder in place on the 40-inch Yerkes reflector, Yerkes Observatory

Photography Has Been Very Important in the Development of Astronomy. Indispensable as the telescope has been in the development of astronomical science, it would have been much less effective if certain auxiliary instruments had not been invented. Among these the photographic plate is of prime importance. Indeed, the improved camera and modern films figure much more prominently in the study of the stars than does direct telescopic vision. With the highly improved, dry emulsion plates and with the very exact driving mechanism of modern telescopes, exposures of surprising duration can be made. Exposures of one hundred hours have been achieved. This permits photographic images to be taken of objects so far away that they send but extremely faint rays of light to the earth.

The Spectroscope Is Invaluable in Astronomical Work. A third instrument indispensable to astronomers in their study of the outer worlds is the spectroscope. The basic principle upon which this device works is simple.



A direct-reading spectroscope

A, triangular prism; *B*, tube with narrow slit; *C*, eyepiece

If a narrow beam of light passes through a triangular prism of glass, it is greatly changed in its passage. Instead of coming out a beam of white light, as it went in, the emerging rays are separated into the colors of the rainbow. This is due to the fact that white light, or ordinary sunlight, is a composite of light waves of a great number of different lengths, ranging from the long-wave red rays to the short-wave violet rays. Now, as the beam of light passes through a glass prism, the short, or violet, rays are bent, or refracted, most. Next to the violet, the indigo and blue waves are bent most, and so on for all the rays up to the red, which are bent least. This causes the different colors of light to be separated, the whole producing a rainbow effect which is known as the spectrum.

In its simplest form the essential part of a spectroscope is a triangular prism of high-quality glass whose faces are plane. In addition to the prism there are two tubes. One of these tubes (the collimator) collects a thin beam of light through a narrow slit, and properly directs it against one of the faces of the prism. The other tube (the observing telescope), provided with a magnifying eyepiece, catches the spectrum produced as the beam emerges from another face of the prism and conveys it to the eye of the observer when he looks through the eyepiece. He thus sees an enlarged, beautiful spectrum showing the colors of the rainbow standing out sharply inside the otherwise dark tube. This separation of the light rays into their various colors is highly interesting from either a scientific or an aesthetic point of view. But if this were all the instrument did, it would be of very little use to astronomers.

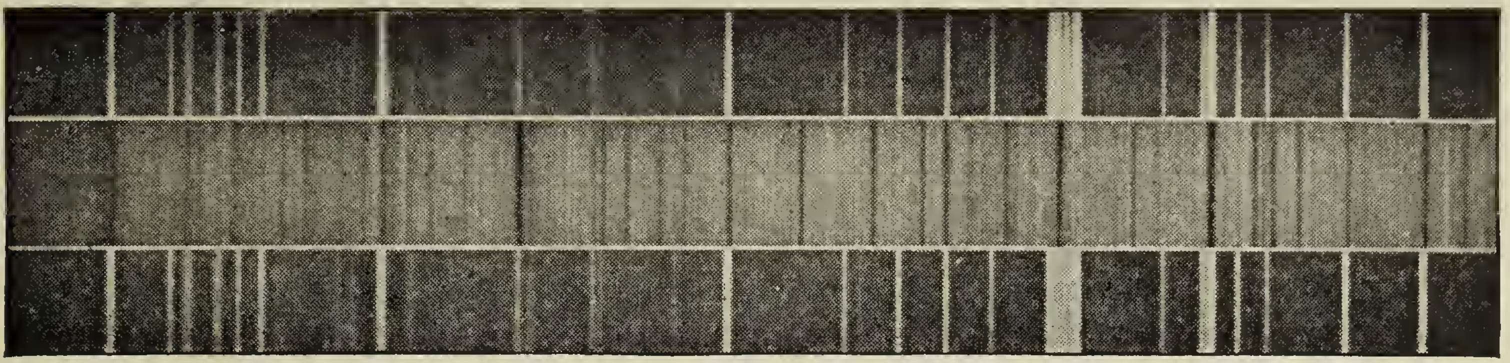
Joseph Fraunhofer (1787–1826), a German lens and spectroscope maker, first became aware of the strange message that this instrument brings to us from the stars. Fraunhofer perfected the narrow slit used to admit a thin beam of light into the spectroscope tube. One day when observing a beautiful spectrum produced by sunlight, he noticed a number of distinct black lines of varying prominence, extending vertically across the otherwise colored spectrum. Wollaston, an English physicist, had discovered some of these lines before. But Fraunhofer noted a great many more of them, which he set about to study carefully. Altogether he detected about six hundred of them. He definitely located the position of several of them on the spectrum and named them after certain letters of the alphabet, a system which we still employ. Later, as a mark of personal recognition, these lines were designated Fraunhofer lines.

As has often happened with other discoveries, the great significance of the Fraunhofer lines was not grasped at all when they were first detected. Indeed, it was not until Kirchhoff's memorable discovery in 1859 that the astounding meaning of these dark lines began to dawn upon the minds of astronomers.

Kirchhoff discovered that when a pure element of any kind, such as hydrogen, is heated to incandescence, and the emitted light is examined with the spectroscope, certain vertical bright lines appear on a dark field. These lines vary in color, brightness, number, and position, depending on the element under observation. Whenever the pattern for any element is determined, the lines are always found to be characteristic and constant when observed under the same conditions. In this way, by means of the spectroscope, any of the elements, when made incandescent, can be identified. This kind of spectrum is called a bright-line spectrum.

It was further discovered that when white light rays emitted by a very hot material are passed through a cooler gas of the same element, dark lines are observed crossing the spectrum in the spectroscope. Furthermore, these dark lines coincide exactly in position and prominence with the bright-line spectrum of that element and with certain of the dark lines located and mapped out on the solar spectrum by Fraunhofer.

Astronomers knew that the sun, like other hot stars, is surrounded by a veil of cooler gas through which the rays from the hot interior have to pass on their way to the earth. Therefore the rays from the incandescent sun must have certain wave lengths absorbed as they pass through the cooler vapor of the same element and must cast dark lines across the solar spectrum. Here, then,



Yerkes Observatory

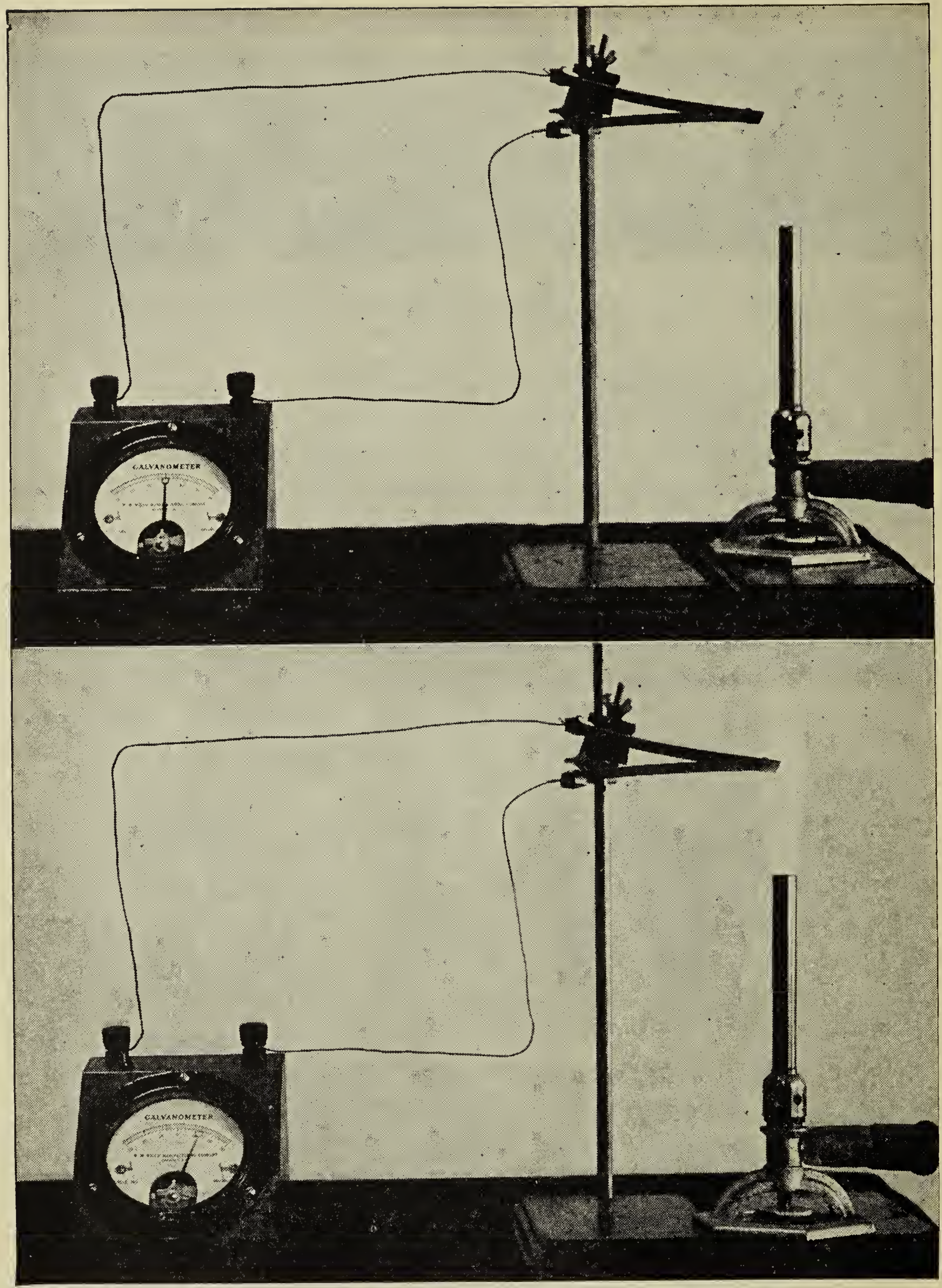
Comparison of a dark-line spectrum (middle) with a bright-line spectrum

was the tremendous significance of the Fraunhofer lines! Here was the key to the agelong riddle as to what the sun and stars are made of! As Abbot says, speaking of the dark lines, "From then till now they have been the master key which has unlocked, one by one, the secret storehouses of knowledge of the universe." Physicists set to work with a feverish enthusiasm to develop bright-line spectra of a large number of the elements found on the earth. By placing these in corresponding position with the solar spectrum and comparing the bright lines of the former with the corresponding dark lines of the latter, the earth and the sun as well as the other stars were found to have many elements in common. The presence of sodium, carbon, iron, zinc, oxygen, copper, calcium, nickel, and magnesium was detected on the sun and, subsequently, that of many other elements.

Perhaps the most interesting development in stellar investigation, however, occurred in the years 1868 and 1895. In 1868 Sir Norman Lockyer discovered certain lines in the sun's spectrum which were not reproduced by any element then known on the earth. Here, then, was an element in the sun apparently not found on the earth. This strange element was named helium from the Greek *helios*, meaning "sun." Later, in 1895, Sir William Ramsay, while examining certain minerals with the spectroscope, detected in them the same gas that Lockyer had found in the sun nearly thirty years before. Certainly no more dramatic moment was ever experienced by man in his quest of the stars than was experienced by Sir William Ramsay on that memorable day. Helium at first was believed to be very rare, but it has subsequently been obtained in large quantities from certain districts in Texas and Colorado and is used chiefly as a nonexplosive gas to inflate dirigible balloons.

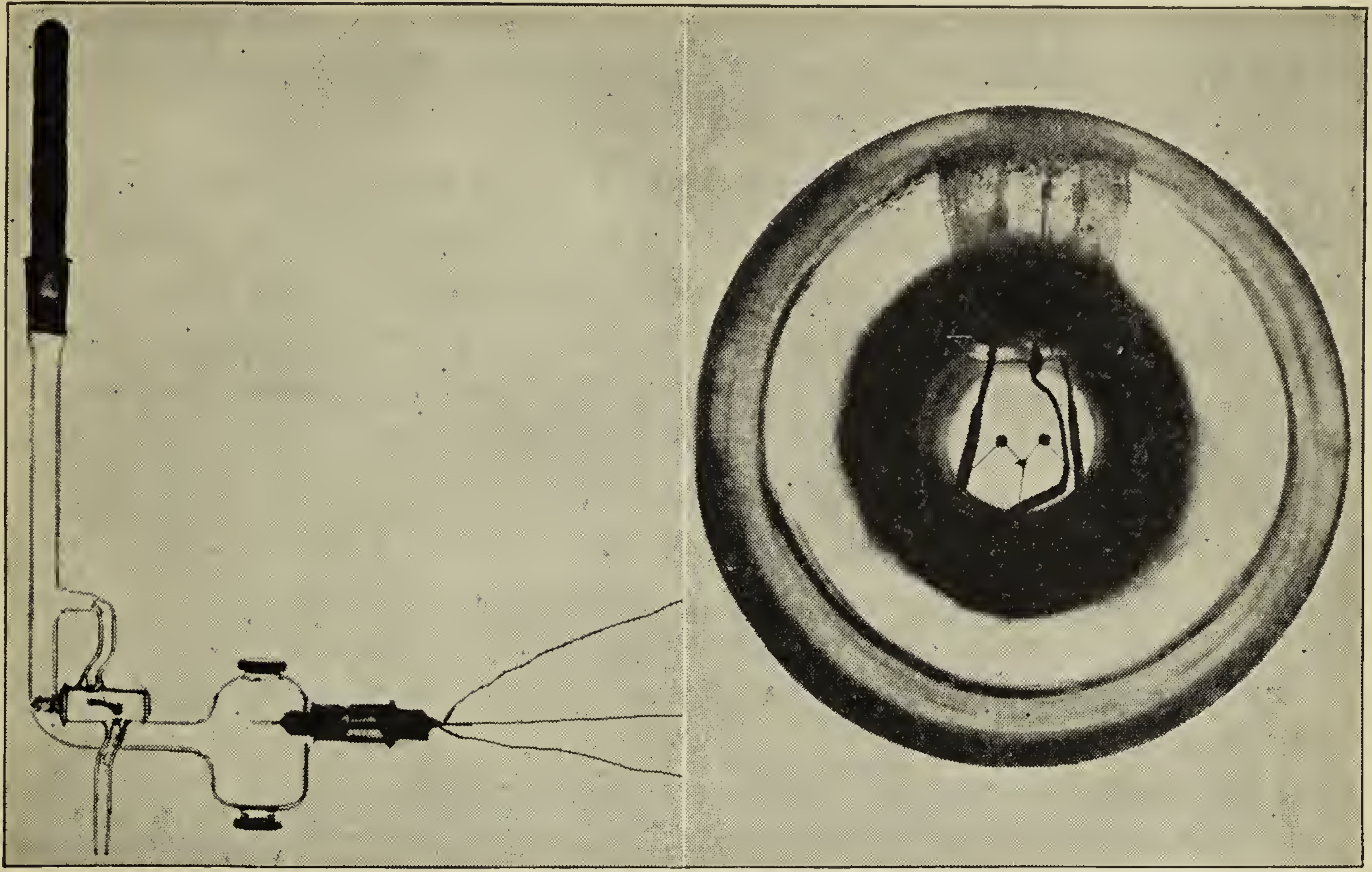
The Thermocouple Is Used Extensively in Astronomy. The last astronomical instrument which we shall describe is the thermocouple. There are many other instruments which are employed by astronomers in their work; but some of them are too intricate in principle to be discussed here.

The essentials of a common laboratory type of thermocouple are two strips


GALVANOMETER
GALVANOMETER

A common laboratory-type thermocouple

Above, before heat is applied, there is no electric current; below, while heat is applied, electric current is produced. (See galvanometer pointer)



Mount Wilson Observatory

Thermocouple used at the Mount Wilson Observatory

Left, side view; the point in the vacuum chamber is the fused wires. Right, looking through the thermocouple as the light passes

of metal fastened together at one end. One of the strips may be copper and the other German silver. The other ends of the pieces of metal are connected to a very sensitive galvanometer with copper wires. A galvanometer is an instrument used to detect an electric current. Since one of the two pieces of metal heats faster than the other, when the point of union of the two metals is heated a feeble current of electricity is produced, which is registered by the galvanometer (see figure on page 34).

An astronomer's thermocouple is an extremely delicate instrument. The essential part consists of two very minute wires fused together at the extremities. One of these is of bismuth; the other is a bismuth alloy containing 5 per cent of tin. This device is set in a blackened metal receiver to make it absorb the star rays more effectively. The tiny wires that form the couple are connected by a copper wire in the circuit of which an exceedingly sensitive galvanometer is set. The weight of such a thermocouple, including the metal receiver and the fused wires, is about that of one one-thousandth of a drop of water. The thermocouple operates in a vacuum to prevent the escape of heat by conduction and convection in the air. The effect of the vacuum on a stellar thermocouple is to increase its sensitivity from fifteen to thirty times. The thermocouple utilizes rays both visible and invisible, and the amount of the deflection is proportional to the degree of radiant energy coming from the star.

So sensitive is the thermocouple used by Pettit and Nicholson that if employed with the hundred-inch reflector it would detect the heat produced by a candle a hundred miles away, were there no atmosphere to absorb the candle rays. When the area of about six square yards of star energy gathered in by the Mount Wilson telescope is focused on the thermocouple, its temperature is increased about one half-millionth of a degree. The current generated is only about one twenty-billionth of an ampere.

Questions for Study

1. What important properties of light have made the use of the telescope possible in astronomical investigations?
2. Distinguish between the two types of telescopes now in use.
3. What is the exact nature of the advantage offered by the telescope over that of the eye alone when studying the heavens?
4. Why has the spectroscope been referred to as the queen of astronomical instruments?
5. Upon what principle does the thermocouple work?

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CHAPTER FOUR

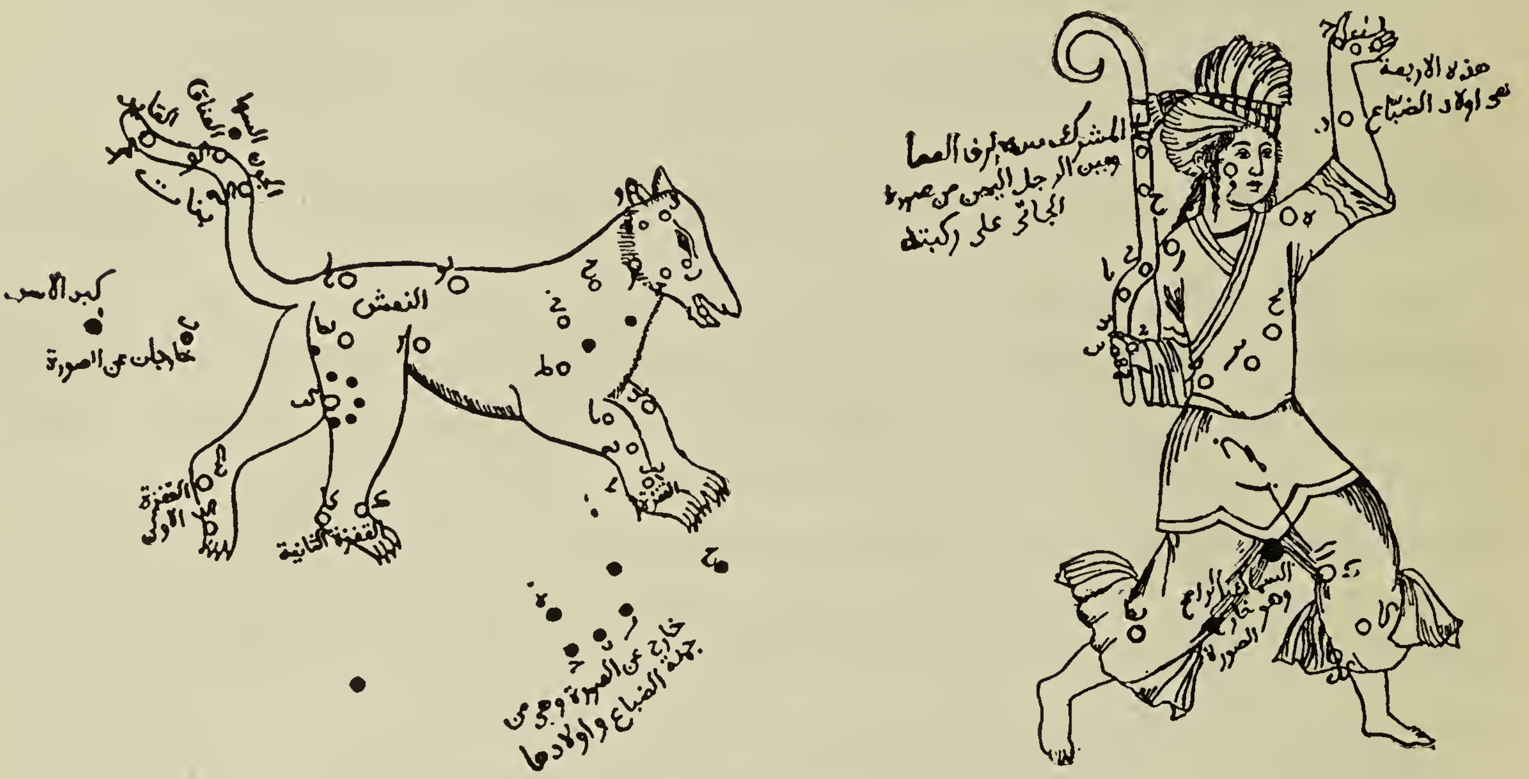
Investigation with Astronomical Instruments Has Changed Man's Understanding of the Stars

Stars Are Suns. Perhaps the most marvelous revelation of the telescope, supplemented by other instruments, has concerned the true nature of the stars. These objects are not gentle, twinkling little bodies set up in the sky, as they appear to be. On the contrary, most of them are huge, surging, tumultuous bodies that go rushing through space with almost incredible speed. In short, the stars are suns, and our sun is a star. Many of them are much larger than our sun, and many of them are thousands of degrees hotter. In fact, our sun, when we judge it relatively, is just an average star.

The Stars Are in Constant Motion. The ancients, we have found, regarded the stars as stationary bodies fixed to a revolving dome. Indeed, it is customary even today for astronomers to speak of the distant stars as "fixed stars," just as if they were stationary in space. So completely did this idea influence men's thinking, that they recognized certain fancied forms in the heavens produced by the outline of stars grouped in apparent proximity. The stars in such a group were called a constellation and frequently were named after some animal or mythological character. The Big Bear, Little Bear, Andromeda, and Orion are examples. This conception is one, however, in which things are not what they seem. Stars appear to be fixed only because the period of human history is so brief compared with the vast aeons of time involved in star changes. In fact, if one had an accurate map of the heavens made at the time when Hannibal with his army crossed the Alps in his advance against the Romans, more than two thousand years ago, to compare with one made today, one would find but slight changes. Yet the stars are really speeding along through space at a tremendous rate.

Careful calculation reveals that the average rate of movement of the stars with relation to one another is about 18 miles a second, or 600,000,000 miles a year. The rates of individual stars vary greatly. Some stars move as slowly as 2 miles a second, while others rush along through space at the enormous speed of almost 500 miles a second.

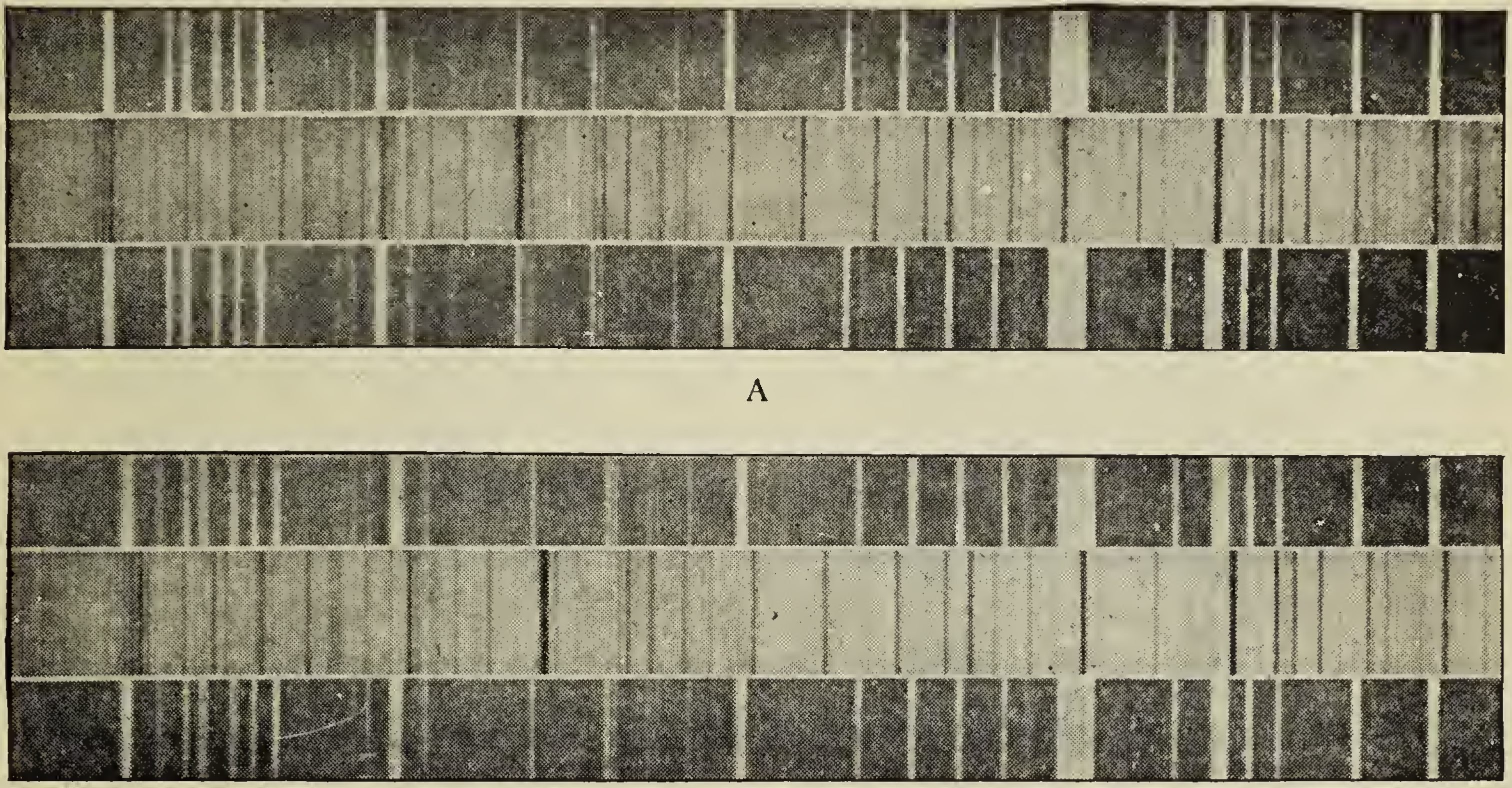
The stars are so far away that this movement is apparent only to the most refined method of observation. It would take thousands of years for this motion to be detected among the distant stars by the average man without the use of instruments. The apparently most rapidly moving star in the heavens is Barnard's star. It is too faint to be seen with the naked eye, and it describes a proper motion. It progresses among its neighbors at a rate of about 10 seconds of arc a year. Such motion would carry it across a visible space in the sky equal to the moon's diameter in 180 years. The stars do move; and in the course of a half-million years or so the whole contour of the constellations, such as the Big Dipper and Orion, will be changed. New names will again have to be conjured out of fancy, if man retains his mythological bent, to designate the appearance of the star groups.



An ancient concept of constellations

Left, the Great Bear; right, Ophiuchus

The Speed of the Stars Is Determined by the Shift of the Fraunhofer Lines. You doubtless have stood on a railroad track and watched a puffing locomotive drawing a long train of passenger cars as it came speeding down upon you. As the engine approached the crossing, it gave a shrill, high-pitched whistle. Then as you stepped aside and the train rushed past, the receding locomotive again whistled. This time, however, the sound came in a much lower pitch and in a seemingly more dolorous tone. It was the same locomotive when going as when coming and carried precisely the same whistle. Why this very evident difference in pitch then? Here, again, things were not what they seemed. The whistle did have exactly the same pitch to the engineer in the cab in both instances. The difference to you was only apparent. As the engine approached you, the sound waves were shortened so far as you were concerned, because more of them reached your ear per second. This raised the pitch of the whistle. Similarly, when the locomotive had passed you and was going in the



A

B

Yerkes Observatory

A, comparison of the absorption spectrum (center) and the bright-line spectrum (top and bottom). B, the dark lines in the absorption spectrum are shifted toward the right

opposite direction, the sound waves were lengthened in proportion to the speed of the train, and fewer of them reached your ear per second. This caused the pitch of the whistle to fall.

So it is with light, which may be considered as waves traveling in space. If the star from which the light is coming is rushing toward us, the light waves are shortened; if it is receding, the waves are lengthened. This is where the spectroscope comes in to help investigators to arrive at the speed of the moving star. Doppler (1803–1853), an Austrian scientist, showed that theoretically the spectral lines made by a moving light are slightly shifted from the position they take when the light is standing still. If the light is approaching, the lines are shifted toward the violet end; if receding, the lines are shifted toward the red end. Moreover, the amount of the shift is dependent upon the speed at which the source of light is moving. The greater the speed, the more the shift. This principle is known as the *Doppler effect.*

Thus, when aided by the telescope to gather in and focus the starlight, the spectroscope tells us of the behavior of celestial objects at almost incredible distances in space.

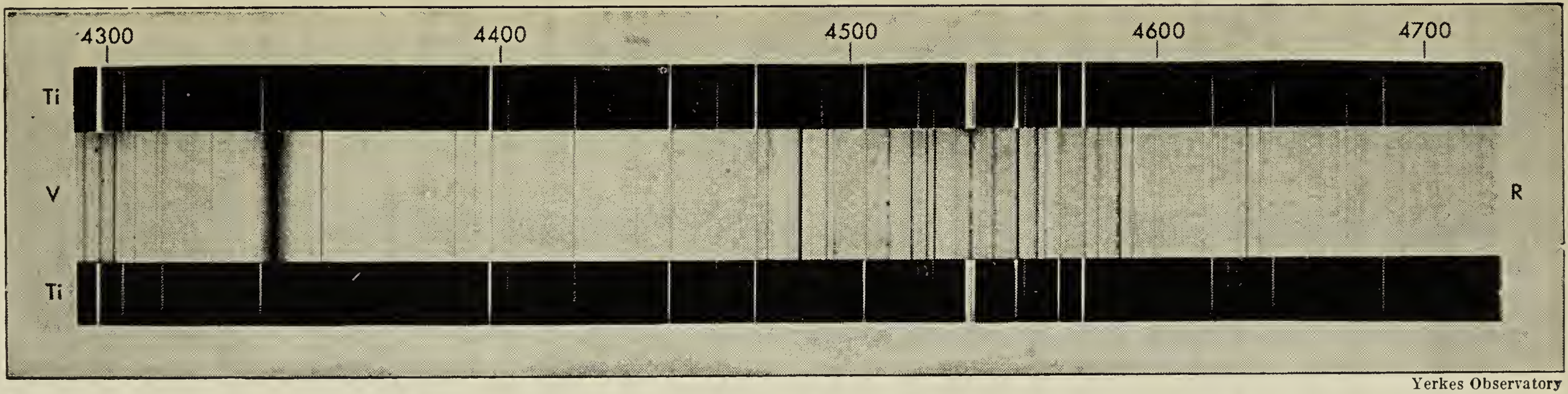
There is one thing, however, that we must always remember about the reports from the distant stars. That is that these reports are in no sense up to date. For instance, any conclusion which we might reach tonight regarding what is going on at this time in the spiral nebula in Andromeda, a million light-years away, would have to be taken with considerable qualification. What we really know is how that giant was behaving when the light that arrives now started from its source a million years ago—long before civilized man existed and when the woolly mammoths were still roaming the arctic plains. This delay in the arrival of star reports, man will probably never be able to overcome. Yet we are consoled by the fact that star histories are believed to be so exceedingly long and most major changes come so slowly that anything which may be taking place on a star tonight quite likely will be very similar to what did happen a million or more years ago.

The Stars Are Very Far from the Earth. One of the most astonishing facts about the stars is their great distance from the earth. The star nearest to the earth, with the exception of the sun, is probably Alpha Centauri, which lies below our southern horizon. To the casual observer it would seem that it could not be more than a few miles above the earth. Yet, when astronomers compute its distance, they find it is so far away that the mile, the unit of distance we are accustomed to use, is entirely inadequate, because the number of miles mounts up so rapidly that our comprehension is overwhelmed. In order to make their numbers intelligible in measuring star distances, astronomers must use an entirely different unit—the light-year, which is about 6,000,000,000,000 miles. Employing this giant yardstick, we find that Alpha Centauri is something like 4.3 light-years away.

Sirius, the Dog Star, is the nearest star visible in northern latitudes and apparently the brightest star in all the heavens. It is 9.1 light-years away, and its surface is twenty-six times as bright as the surface of our sun. Only seven single or multiple star systems are known to be less than 10 light-years from us. Some stars of the Big Dipper are 70 light-years away; the North Star, 300; and Rigel (13,000 times brighter on its surface than the sun), almost 500 light-years distant from the earth.

Visible Stars Are Believed to Have a High Temperature. One of the most surprising characteristics of the stars is the high temperature developed by some of them. In our best electric furnaces it is possible to produce temperatures of about 3500° C. Yet the sun at its surface is considered to be about 6000° C. The surface temperature of red stars, according to some authorities, may be as low as 1500° C, but that of white stars is many times higher than that figure. Sirius, the brightest-appearing star in the sky, is estimated to be 11,000° C on the surface, Vega 14,000° C, and Rigel 16,000° C. The surface temperature of the hottest star known, according to Jones of Cambridge University, is 60,000° C, and that of the coolest known is about 2000° C.

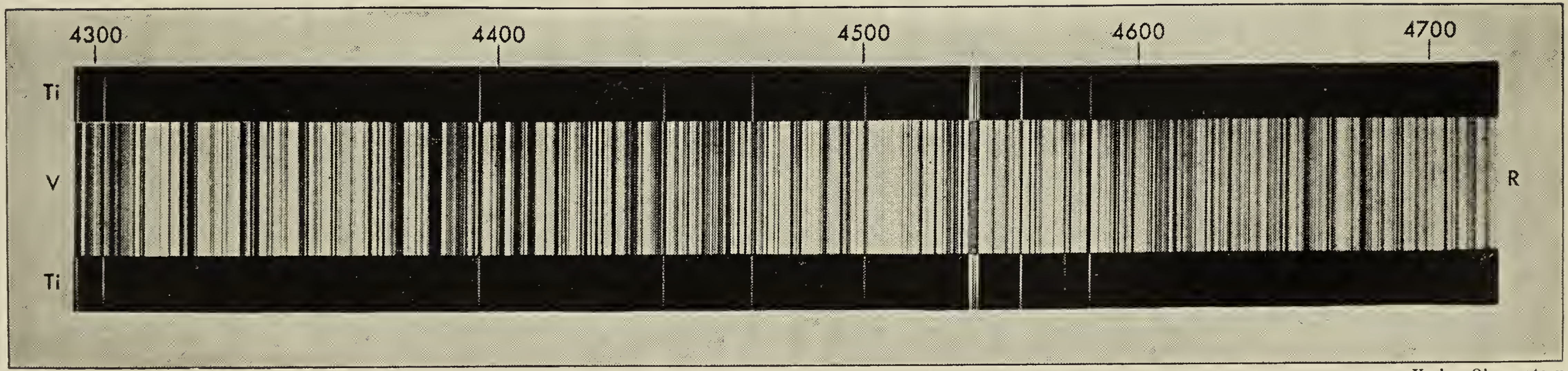
Judgments as to the internal temperatures of stars, although of course not known with any high degree of accuracy, are based on what is believed to be


4300
4400
4500
4600
4700
Ti
V
Ti
R

Yerkes Observatory

Spectrum of Eta Leonis, compared with the laboratory spectrum of titanium

The star is shown to be moving away from the earth at a speed of 18 miles per second


4300
4400
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Ti
V
Ti
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Yerkes Observatory

Comparison of the spectrum of Arcturus and the laboratory spectrum of titanium

Arcturus is shown to be moving toward the earth at a speed of 11 miles per second the behavior of star matter. From this evidence the centers of some of the stars are estimated to be 20,000,000° C or more. Such a temperature is so high that our comprehension fails to grasp its significance, and we are impelled to ask, "How can such heat be developed?"

Perhaps no solution which is above criticism can be offered at this time. Helmholtz (1821–1894), a great German physicist, advanced the idea that the sun's heat, and hence that of other stars like it, is produced by contraction. As the materials comprising these bodies slowly settle together, great heat must be generated because of the effects of compression. By the mutual attraction between all the parts, all material in a star tends to be drawn toward its center, just as everything on and in the earth is drawn toward its center. The tremendous weight of the outer parts of a star resting on those below would develop an enormous pressure. This weight would tend to compress and hence contract the whole mass of the star, and in the process stupendous amounts of heat would result. This heat, Helmholtz believed, was what kept the star shining. Helmholtz's idea seemed perfectly plausible until the physicists and astronomers began to examine the evidence.

The heat-producing results of this contraction have been estimated for our star, the sun. Assuming, as astronomers do, that it contracted from a very much larger dimension to its present size, it is believed that enough heat to keep it radiating at its present rate for 20,000,000 years would have been generated from this source.

The solar system, however, from evidence to be considered later, is believed to be very much older than 20,000,000 years. The age of the earth itself is estimated to be at least 1,500,000,000 years. There is considerable evidence, too, that the sun has kept the earth at very nearly its present temperature for most of this time. In other words, the sun has radiated into space something like one hundred times more energy than could have been derived from all the effects of contraction. Consequently contraction, the astrophysicists tell us, must have been supplemented by another source of energy generation.

Calculation reveals that the mass of the sun is continuously being slowly reduced by the energy which it radiates. In short, some of its mass is believed to be transformed into energy of radiation. If such a transformation does take place, then the sun could have shone during the whole age of the earth and still have more years ahead to continue its radiations than it has years behind.

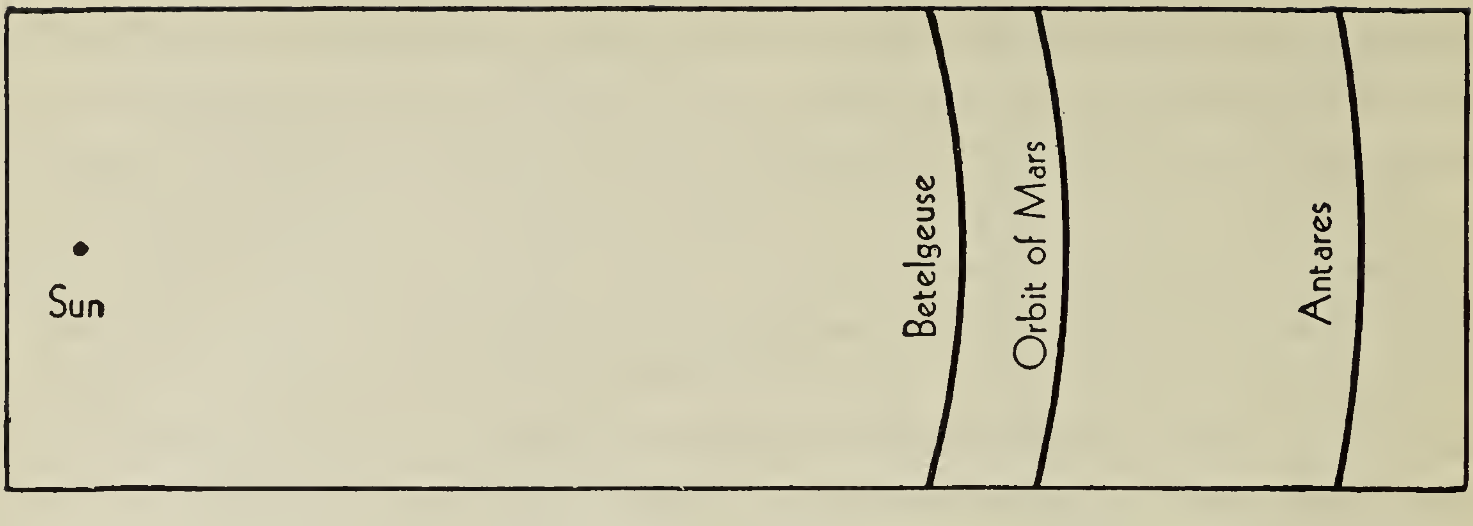
Students of the problem believe that this transformation must be the explanation for the great amount of heat radiated. It has been found, as we shall see in a later unit, that heavier atoms may be built up out of hydrogen. Physicists now generally believe that four hydrogen atoms must combine to make each helium atom. But they can weigh hydrogen and helium atoms with great accuracy, and, strange to say, find that in this combining process $\frac{1}{130}$ part of the whole mass has disappeared. It is believed to have disappeared as matter and to have appeared as energy. Now if the sun had originally been composed of hydrogen, and this had been turned into helium, the energy believed to be liberated in this transformation would have kept the sun shining at its present rate for more than 100,000,000,000 years. Some energy, too, would have been produced as other elements heavier than hydrogen were combined; but most of it is believed to have come from the synthesis of more complex elements from hydrogen. So this transformation—building heavier elements from lighter ones, particularly hydrogen—is now believed to be the chief source of the great energy found in the stars. Dr. Henry Russell of Princeton University, who is one of our most eminent astronomers, says, "There can be no doubt, then, that hydrogen is not only 'the raw material of the universe'—as Eddington called it years ago—but the fuel of the stars, which keep shining by building up heavier atoms out of it."[1] Gamow has recently estimated that the sun is still about 35 per cent hydrogen and, at its present rate of consumption to form helium, the supply would last for about 10,000,000,000 years.

Except as an indication of how far away stars are, the total amount of heat received from them by the earth is almost inconsequential. On an average the entire amount of heat sent to the earth from a star similar to the sun is just about equal to that which the sun itself radiates to a single square yard of the earth's surface. The full moon sheds one hundred times as much light upon the earth as all the stars together.

There Are Three Main Types of Stars. It has already been noted that there are wide differences among stars. They vary greatly as to their rate of movement, temperature, and distance from the earth. They are also widely variable as to size and internal condition. For purposes of classification, astronomers have roughly separated them into three groups, which they have designated as the red giants, stars of the main sequence, and the white dwarfs.

In order to understand these different types of stars, we must discuss atomic structure briefly at this time (see page 151). According to present interpretation the atom is composed of heavy nuclei with electrons, much lighter, revolving about these nuclei, perhaps in some such manner as the planets revolve about the sun. Moreover, not only the weight of the nucleus but the number of surrounding electrons increases greatly as one passes from the

[1] Henry Norris Russell, "The Fuel of the Stars," *Scientific American*, Vol. 157, p. 13. (1937)



Relative size of the sun and some of the larger stars

lighter elements to the heavier ones. Finally, between the speeding electrons there is thousands of times more space than is occupied by the nucleus and electrons themselves.

With these preliminary statements we shall now return to the matter of star types. The reader must not get the idea that the difference between the three types is a sharp and distinct one. As Jeans, the great English astronomer, puts it, "The sky is not quite so simple as this." In fact, there is a gradual transition between the two groups of larger stars. This transition, however, so far as is known, does not hold between either of the two larger types and the dwarf stars.

The Red Giants. The red giants are distinguished by their red color, relatively low temperature, and gigantic size. In some of these giants the central temperature may be as low as 1,000,000° or 2,000,000° F. Their surface temperature is, of course, considerably lower, which accounts for their color characteristics. Under these temperature conditions the electrons are not stripped off the nucleus by the raging heat, that is, by the enormous speeds with which the atoms are constantly colliding with one another, as they are in hotter stars. Thus the atoms remain of large size. The tendency of the unstripped atoms to remain intact and thereby to require much "elbow-room" is believed to be the chief reason why the stars of this type are so huge in size.

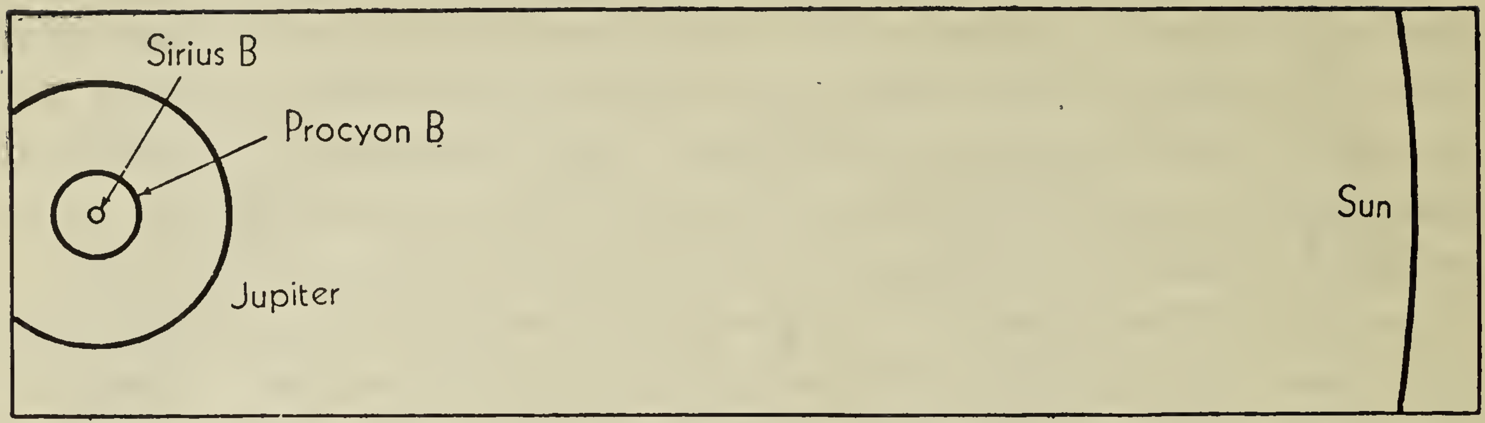
Some of these giants have been measured and their size is astonishing. Betelgeuse, a prominent star of the winter sky in our latitude, is estimated to be 25,000,000 times as big as the sun. That means that our earth, which impresses us as being large, is but a spherical toy in comparison. In fact, about 25,000,000,000,000 of our earths, if they could be condensed into one mass without expansion resulting from temperature changes, could be safely tucked away within the outer surface of Betelgeuse. But this star is by no means the largest of the giants. Antares, of the stars whose sizes are known, claims that honor. Its diameter is 450 times that of the sun, and it has a volume over three and a half times that of Betelgeuse. Like Betelgeuse, it is gaseous in nature, and its density is estimated to be so low that on an average the matter of which it is made is "a thousand times as tenuous as the air we breathe."

Stars of the Main Sequence. This group is by far the most numerous of the three types, comprising about 80 per cent of all the known stars. The sun is a main-sequence star. As might be expected, they vary widely in some respects; but all are similar, it is believed, in having about the same central temperature. Here the heat is regarded as being sufficient to strip off all the outer electrons from the atoms. The majority of the atomic nuclei, however, still retain their two inner electrons. This condition permits these partially stripped atoms to be pressed much more closely together by the weight of the superimposed layers of star material than they are within the giant red stars. So dense is the material here that a cubic foot of it must weigh some tons, but just how much no one knows.

The main-sequence stars, while considerably larger than the white dwarfs,—the next group to be mentioned,—do not show an enormous range of sizes. They do show the utmost diversity of characteristics, however. Their estimated weights range through the whole gamut of known star weights, and their colors through the whole array of colors from the dullest red to "vivid violet." The effective surface temperatures may vary from lower than that of the sun to about 50,000° C. As Jeans says, they run through the "whole range of stellar luminosities from the searchlight to the glowworm." In this sequence our sun is a yellow-colored star, and, although not a piercing searchlight, it is also not a lowly glowworm. Perhaps it would compare more favorably with an automobile headlight.

The White Dwarfs. In many respects the white-dwarf stars form one of the most interesting groups in the heavens. Their centers are believed to be ten, twenty, and perhaps even fifty times hotter than those of the main-sequence stars. Also, the high pressures which exist in these white dwarfs have recently been shown to have disrupting effects on the atom. No atoms can escape the disrupting power of such great heat. Here the electrons are all believed to be stripped off and the broken-up debris of electrons and nuclei go dashing about helter-skelter without any semblance of coherence.

Most stars do not vary greatly in mass. Their range in mass lies for the most part somewhere between one fourth and ten times that of the sun. The largest white dwarfs are about twice the size of the earth, while the smallest are about one-fourth as large, or approximately the size of the moon. Although



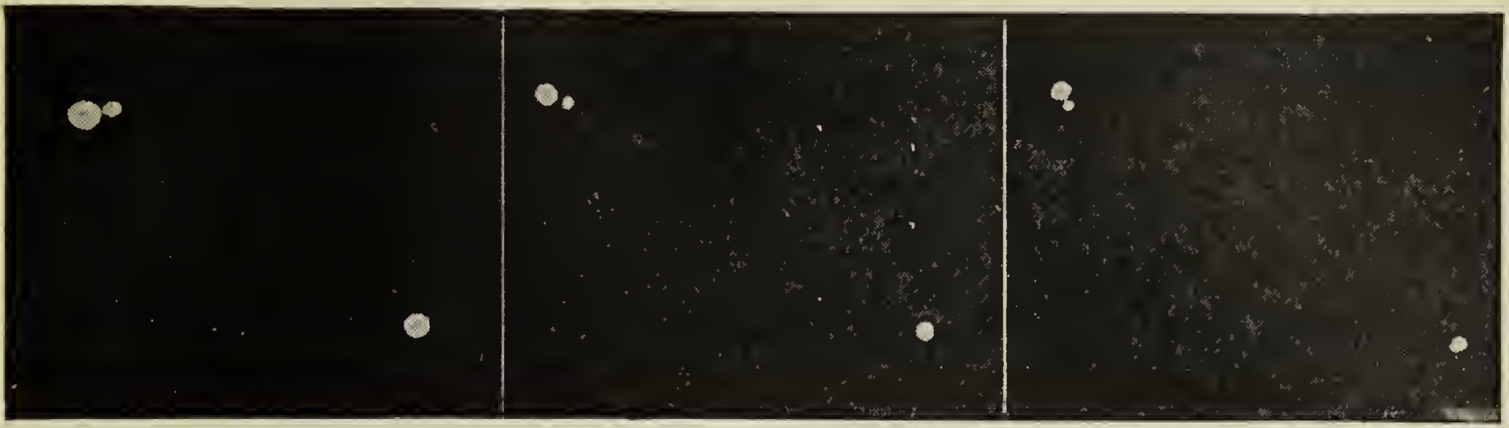
Relative sizes of some of the white dwarf stars and the sun

these pygmy stars are but planetary in size, their estimated mass mounts to an astonishing figure. In this respect they surpass the earth from 150,000 to 800,000 times. The Dog Star, Sirius, has a companion of the white diminutive type which is only about twice as large as the earth. Yet this star weighs almost as much as our sun. It is believed that tremendous heat and pressure have torn the atoms of this star to pieces, and the enormous weight of the huge mass has literally jammed the atomic debris so closely together as to reduce the size of the body to these dimensions. It is believed that this way of packing the substance of a star together has produced all the white dwarfs.

Such close compression means that the density of these dwarf-star substances is great. The average density of the earth is about 5.5 times that of water, but the companion of Sirius has a density about 30,000 times greater than that of water. Jeans tells us that if materials on the earth could be packed as densely as these stars are, we could carry about a hundred tons of tobacco in a tobacco pouch and several tons of coal in a vest pocket. Dr. Kniper of the Yerkes and McDonald observatories has recently reported a white dwarf designated as Wolf 457 which probably surpasses in density any other known star. A cubic inch of this stellar body is estimated to weigh 18,000,000 pounds. With such density a piece of it could not be supported by any earthly substance. If it were placed upon the surface of the soil, for instance, it is believed that it would drop right through the earth material like lead through air.

The number of known white-dwarf stars is not great. Only about ten good examples are known at the present time. But no one is sure what the actual number may be. Their size is so small that they cannot be seen at great distances even with the aid of a powerful telescope.

Many Stars Are Multiple. That stars often go in pairs, triplets, or even quadruplets is an interesting fact brought out through observation and study. Frequently these twins or larger groups are sufficiently far apart to be detected



Yerkes Observatory

Three photographs of the triple star Kruger 60

Conspicuous orbital progress is shown, as the stars revolve about one another

by the telescope. Epsilon Lyrae is an excellent example of this. In this case, by close observation, the eye detects two stars. Closer observation, with a telescope, reveals that each of these two stars is really two of nearly equal brightness. Altogether there are thousands of binary and multiple stars. Some astronomers believe that at least one third or more of the stars have circling companions.

More often these stars are single binary systems, that is, simply a single pair. Occasionally they are far apart, and the revolution about their common center of mass requires thousands of years—so long, indeed, that since they have been discovered, but a small fractional arc of the orbit of one about the other has been traversed. In other cases the orbit may be so small that the revolution is completed within five or six years.

Many Stars Are Variable. A star whose brightness is observed to change is known in astronomical language as a *variable star.* It is probable that most stars vary to some degree. Even our comparatively staid and steady sun is believed by some astronomers to vary slightly in brightness. Contrasted with these, however, there are many other stars whose variation in brightness is one of their prominent characteristics, the study of which has become a challenging aspect of astronomy.

The immediate cause of this variation is believed to be a fluctuation in the surface temperature of from 15 to 20 per cent. "But what," one hastens to ask, "could produce a regular and even variation of such magnitude as would cause the surface temperature of a huge star over billions of square miles in area to rise or fall almost a thousand degrees in so short a period of time, and then, as Dr. Henry Norris Russell puts it, 'come back where it was at first, and do it again and again?'" The same authority tells us that the regularity of period has given us a clue, and he explains it by using familiar illustrations. He says:

There are two types of oscillation which we use, in everyday life, as time-keepers —motion of a body under gravitational force, like the pendulum of a clock, and motion under elastic forces, like the balance-wheel of a watch or a tuning-fork. Both forces are operative in a star—gravitation pulling it together, and the elastic force of gas-pressure keeping it from collapsing. An ordinary star is in equilibrium. But suppose we could take such a star and suddenly compress it in every part, so that it was reduced to 90 per cent of its original diameter. Gravitation would [then] be stronger, since all parts of the star are nearer together, but a simple calculation shows that the gas-pressure would be still more increased. So, if the star, after being held at the smaller diameter, were let go, it would expand to its original size. When it got there, all parts of it would be moving outward (the surface fastest) and it would overshoot the mark—like a pendulum drawn to one side and let go—and keep on expanding till it got as much too big as it had been too small. In this condition the gas-pressure would be too weak to balance gravitation—the star would contract again, and return to the state from which it had started, just as a pendulum swings back to the point of its release. Successive oscillations would take just the same time —again like a pendulum. Such a change in size of a star is called pulsation.[1]

Pulsating stars, like all others, are in the gaseous state; so when they are at their smallest, the gases in the interior are compressed and hotter than the average, and when they are at their largest, the gases are expanded and cooler. Once begun, this pulsating rhythm continues for a very long time; for, although there is some friction between the particles of gas, the slowing-down effect of friction on the general expansion and contraction movements is small.

The surface movement of these huge, bright, pulsating stars is enormous, as one would suspect. For stars with periods of three or four days, the diameter, at the time of greatest expansion, has been estimated at 17,000,000 miles, which is almost twenty times that of the sun. For stars with periods of forty days, the diameter probably exceeds 100,000,000 miles. The surface of the former stars, as revealed by the Doppler effect, surges in or out at the rate of about 25 miles per second, or more than 2,000,000 miles a day. For the largest of this type of star computed so far, the surface is estimated to move in or out at the rate of about 40,000,000 miles a day—a distance almost half that from the earth to the sun.

What set these stars to pulsating in the first place is, of course, problematical; but it can readily be seen that, once begun, the rhythmic movements could well continue for a very long time.

Another group of variable stars are the supernovae. The most prominent characteristic of these stars is that they manifest a remarkable outburst

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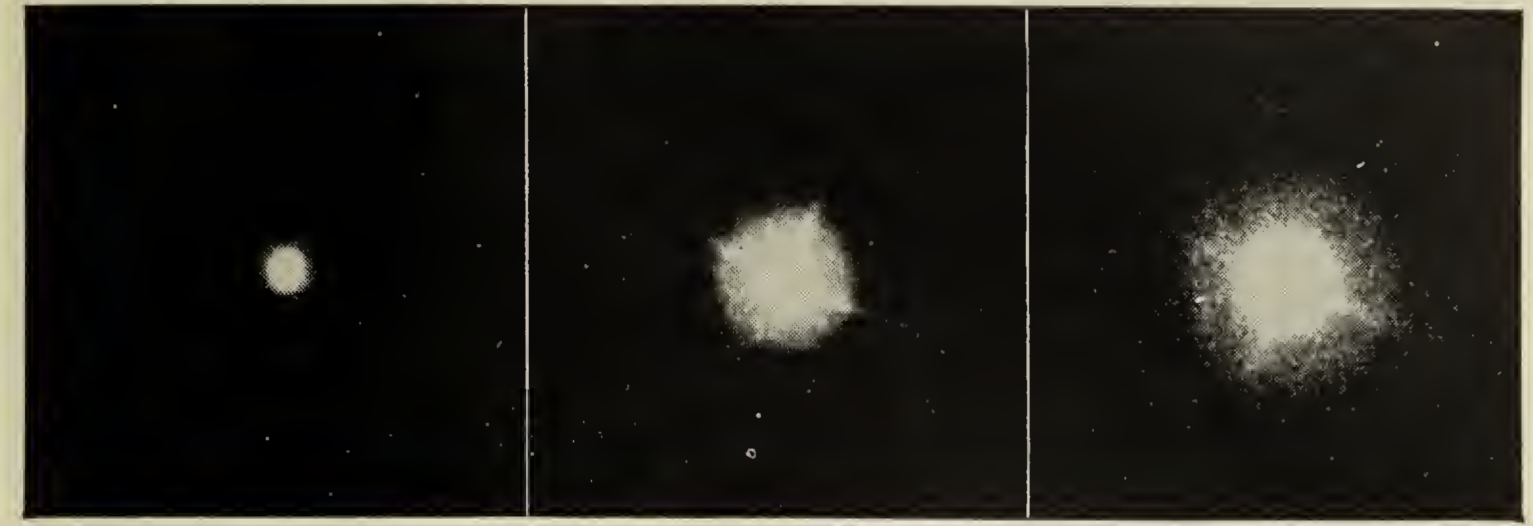
[1] Henry Norris Russell, "Pulsating Stars," *Scientific American*, Vol. 158, p. 84. (1938)



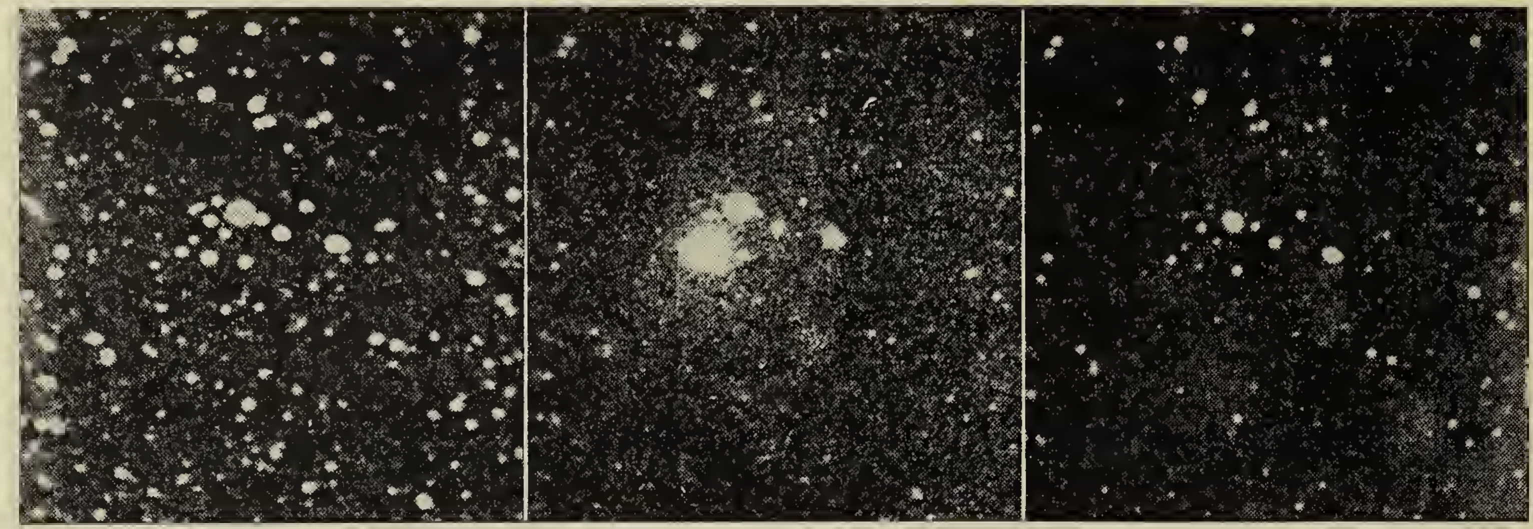
Mount Wilson Observatory

Three photographs of the expanding ring about Nova Aquila, No. 3

Left, July 20, 1922; center, September 3, 1926; right, August 4, 1931

of brightness and then usually fade away to become, after a few weeks, invisible to the unaided eye. Within the records of man, the first star of this type to be observed was seen by the Greek astronomer Hipparchus, one hundred and thirty-four years before Christ. The second one to be seen, and perhaps the most brilliant one yet observed, was sighted by the Danish astronomer Tycho Brahe in 1572. He was returning home for supper after a day's work in his observatory when he happened to lift his face toward the heavens and beheld this brilliant new object. It was then among the brightest of the stars. It occupied a position in the constellation of Cassiopeia where no bright star had been visible before. At first Tycho Brahe could not believe his senses. He thought he must be suffering from some hallucination. He, therefore, called his servants to corroborate the strange sight; and he was convinced only after their testimony had been added to his "that this marvellous object was no mere creation of the fancy, but a veritable celestial body—a new star of surpassing splendour which had suddenly burst forth." The star grew brighter and within a few days was so brilliant that it could be observed in the daytime with the unaided eye. In fact, this star, when at its brightest, is believed to have surpassed the radiant planet Venus. It is now thought probable that this star is identical with a faint star of the fourteenth magnitude in Cassiopeia. If this assumption is correct, it has decreased at least seventeen magnitudes in brilliance, or six million times, since its historic and record-breaking outburst.

With improved astronomical instruments and more careful study of the heavens, some forty supernovae have been seen, most of which were located in distant star systems far beyond our own galaxy. During the past three or four years astronomers have sighted one or more annually. In contrast to the supernovae many *ordinary* novae have been observed within our own star



Yerkes Observatory

Three photographs of the variable star Nova Lacertae

Left, August 7, 1907, before the outburst, as a thirteenth-magnitude star; center, December 31, 1910, about seventh magnitude; right, September 29, 1911, eleventh magnitude

system. These novae behave much like the supernovae, but their flare-up is much less violent and the star is not destroyed in the outburst.

Virginis, to return to the supernovae, during its brilliant explosion in 1936 reached an estimated velocity of expansion of 3700 miles a second, or more than 13,000,000 miles an hour. This nova is computed to be about 7,000,000 light-years away. So what was recorded by our astronomers for this superstar in 1936 was stale news, seven million years old, on the star itself.

In the same year Nova Lacertae, 2600 light-years away, burst into celestial prominence. The explosive action of this star threw off four distinct shells of glowing gases. Two of them traveled outward at a rate of over 2000 miles a second, and the other two reached a maximum of well over 1200 miles a second.

So far no fully satisfactory theory as to the nature of these stellar cataclysms has been offered. Some astronomers have suggested a grazing collision of two stars as the cause; others have conjectured that two stars might have approached close enough to set up huge disruptive tides that tore great masses of substance from the surface; still others feel that there might have occurred some tremendous release of energy within the atoms of the star itself, which resulted in the colossal explosion observed. Whatever it is, "it cannot be a deep-seated effect, for it is too sudden and ephemeral. The central portions of the star are probably not affected by the great display at the surface."[1]

The flare-up in brightness and the recession of these stars generally take place within a period of six months. However, Kepler observed one in 1604 which was as bright as the planet Jupiter and established a record of visibility to the unaided eye of about two years.

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[1] Alfred H. Joy, "The Stars in Action," *Annual Report, Smithsonian Institution, 1928*, p. 184.

The Stars in Our System Form a Galaxy. When one gazes into the sky on a clear, moonless night, one is struck by the multitude and variety of stars that greet his vision. Some are large and shine with a clear blue light; others are smaller and less bright. Finally, there are those that, because either of their internal condition or of their extreme distance, appear like tiny, indistinct points of light. Yet, as has already been stated, astronomers tell us that we can see at one observation only about two thousand stars with the unaided eye. With the telescope myriads more of them are brought into view, and the estimated number grows enormously. No one knows positively, of course, how many stars there are in our system. They are so numerous that it would scarcely be possible for a single person to make even what could be called a beginning in counting them during his whole lifetime. Besides, it is probable that many are so dim and far away that they cannot be detected even with the most powerful telescope. Particularly is this true of the dwarf stars. Nevertheless, on the basis of the number of stars found in certain parts of the heavens, the late Dr. Plaskett estimated that the total number of stars in our system is about 200,000,000,000. The total mass is put at about 160,000,000,000 times the mass of our sun. To make the facts more vivid, there are, if Plaskett was correct, about 100 stars for every living person on the earth today. All these stars, together with their accompanying bodies, such as planets, planetary satellites, comets, and nebulae, we designate as our *galaxy.*

When we remember the size of our sun and the vast distances between the stars, the immensity of our galaxy begins to dawn upon us. Despite the enormous number of stars in our system, however, its boundaries are so far-flung that the average density of matter is very low. Adams of the Mount Wilson Observatory tells us that if the stars could all be ground up and their substance distributed evenly through space, we should find only about one ounce of matter in a volume 32,000 times the size of our earth.

Our galaxy is not without form, as it appears to be to the casual observer who is viewing it from the earth. Even the ancients observed a misty, gauzy, cloudlike streak extending across the heavens like the arc of a great circle. Because of its indistinctness it came to be known as the Milky Way. Hipparchus was right, but astronomers had to wait for more detailed evidence until Sir William Herschel arrived on the scene. This enthusiastic stargazer noticed that the areas of the heavens studied in the region of the Milky Way contained many more stars than those areas farther away. Not only was this true, but as he moved his telescope in either direction, at right angles to the Milky Way, the number of stars in a given area became less and less. The results of Herschel's study and the study of later astronomers have led to the conclusion

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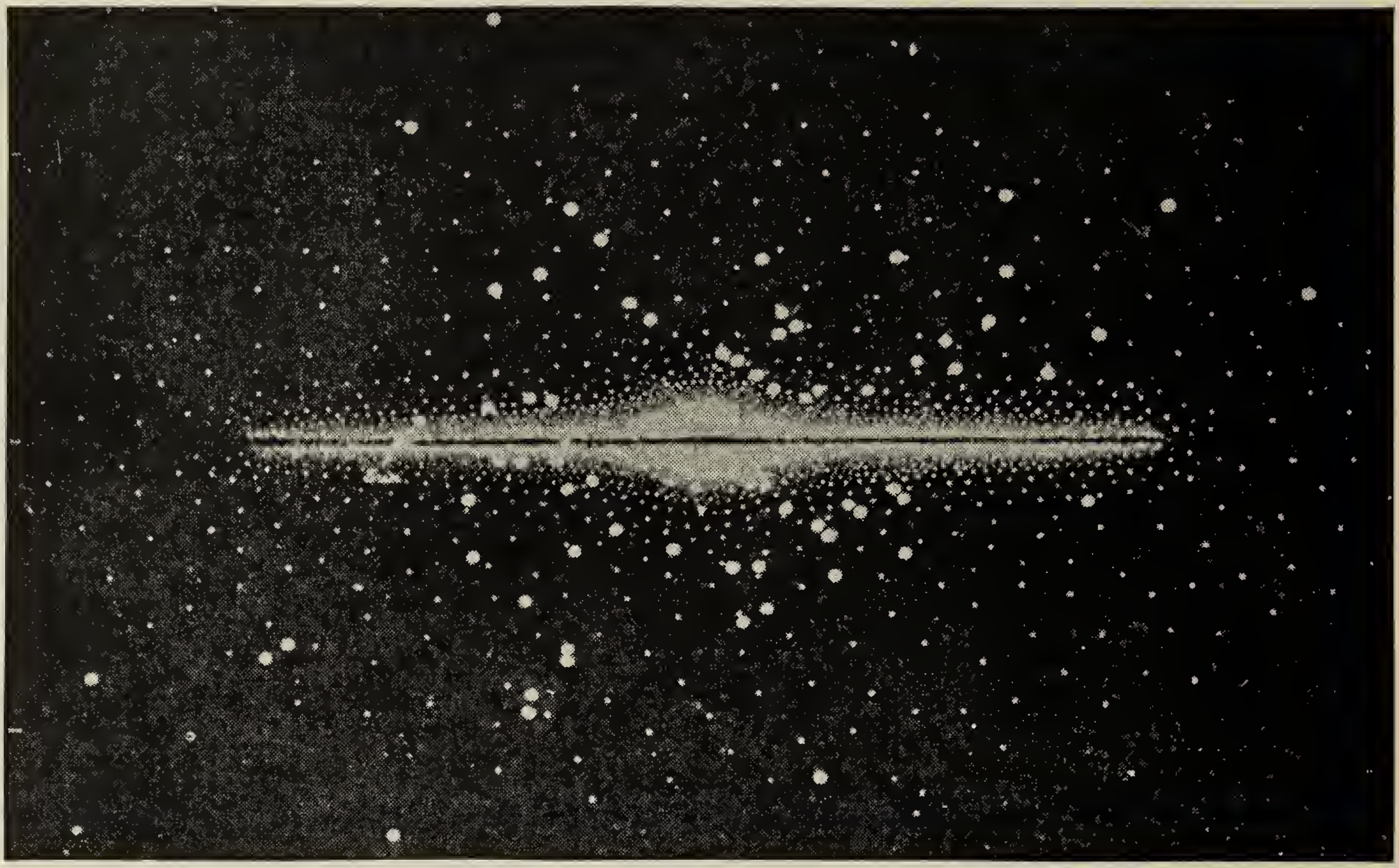


The Scientific Monthly

Model of our galaxy by Plaskett

that our galaxy has the form of a huge watch somewhat bulged out on both the face and the back, and that the distance from edge to edge is much greater than it is from back to face. As a result, when a person looks out through our universe in the direction corresponding to the plane of the flat watchcase, he sees the Milky Way, which is a luminous effect produced by the great number of remote stars in his line of vision. But when he looks out toward the poles of our galaxy, that is, at right angles to the plane of the Milky Way, the sky seems much blacker, both because the distance through the star groups is much shorter and because the stars are more thinly distributed in space.

One estimate of our galaxy gives the distance through the plane of the Milky Way as 100,000 light-years. To comprehend this figure is difficult. It may help to say that a light ray that has just emerged from our galaxy, having passed completely through its long axis, was almost at its journey's end when Moses led the children of Israel across the Red Sea; the time of its passage was well spent when the Cro-Magnon men were decorating the sides of their cavelike homes with the first crude drawings of wild beasts; and it was speeding along deep within our galaxy when the Neanderthal men were out hunting woolly mammoths and rhinoceroses.

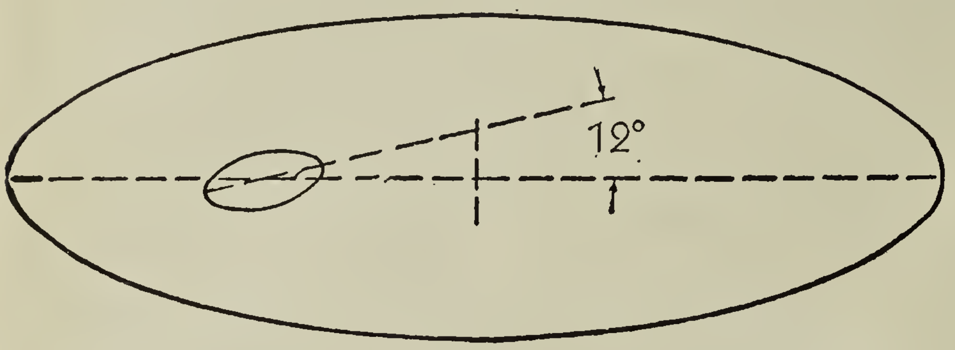
The distance through the short axis of our galaxy, or from the face to the back of the "cosmic watch," is much less. This has been estimated as about 15,000 light-years.

Mount Wilson Observatory

Spiral nebula in Andromeda as seen from the Mount Wilson Observatory

Within this system the sun was formerly believed to occupy a somewhat central position. More extensive and accurate observations, however, have shifted the position of the solar system to a point about 25,000 or 30,000 light-years out from the center and in the general direction of the rim, though slightly north of the central plane.

Modern investigations have revealed that the stars comprising the galaxy are all rotating about a point in the center which is their common center of gravity, just as the planets revolve about the sun. Moreover, like the planets, those stars nearest the common center revolve faster than those farther out. The sun moves in its galactic orbit about 165 miles a second, and it would require something like 225,000,000 years for it to complete one revolution. This type of stellar motion, as the reader will readily observe, is movement on a much grander scale and is quite different from movement with reference to other near-by stars.



Relative position of the solar system in our galaxy

The small ellipse, representing the solar system, is much enlarged

Stars Appear in Clusters. The stars within our galaxy do not appear to be evenly distributed. Sometimes they seem grouped more or less irregularly into immense clusters. The Hercules globular cluster is one of those with which we are best acquainted. In this great star aggregation the suns when photographed appear so thick and close together as to form a veritable star cloud. An exposure of the star cluster in Hercules made with the hundred-inch reflector at Mt. Wilson shows at least a hundred thousand suns. Indeed, if all the fainter stars could have appeared on the photographic plate, the number might easily have run into the millions. The distance of the cluster is estimated at 33,000 light-years. Yet this great group of stars when detected with the unaided eye appears as only a faint, fuzzy star. The telescope reveals several hundred of these star clusters within our galaxy.

With star groups apparently so dense, it would seem that the individual stars must be relatively very close together. And it is true that the stars in the center of one of these star clusters are closer together than in other parts of the galaxy. But even in the very heart of a dense cluster like that in Hercules, the average distance between suns is something like 100,000 times the distance from the earth to the sun, or 9,300,000,000,000 miles.

Star Collisions May Occur. Despite the great distance between the suns, cosmic accidents may occur. Stars do not retain indefinitely their relative positions in the heavens. They are all restlessly swarming about among one another under the spell of their own inertia and the complex pull of their neighbors on every side. Stars within as well as outside these great clusters may move for perhaps thousands of years in one general direction and then slowly curve, change their course, and move off in another direction. Their speed varies widely. Some of them rush along at a velocity of 200 miles per second; others move very much more slowly. The average rate is about 18 miles per second. Our sun, dragging all its planets with it, is lumbering along leisurely in the general direction of the constellation Hercules at about 12 miles per second.

Mount Wilson Observatory

Star cluster, Canes Venatici

Learning that the stars are all moving in this manner among themselves, one may well ask whether there is not great danger of a star collision. This is possible, as already indicated, but certainly it does not often occur. Considering the great volume of the universe and the number of stars it contains, it has been estimated that, according to mathematical laws, a cosmic collision during the great aeons of time does take place occasionally. The probability comes out one in about a quadrillion years. Thus it will be seen that one need not be overanxious. The likelihood that such a catastrophe will occur to the sun is millions of times more remote than the probability that one will be run down by an automobile in the street.

Questions for Study

1. How do the elements forming the stars, so far as these elements are known, compare with the elements known on the earth?
2. How has the study of the stars within our galaxy affected man's conception of the extent of space?

3. How *up to date* is our knowledge of the stars?

4. Contrast the sun with other stars in our galaxy.

5. What distinctions should be made between the meanings of the following terms as applied to stars: (1) matter, (2) mass, (3) density, and (4) volume?

6. What different types of information about the stars may be gained through the application of the Doppler effect?

7. What is believed to be the principal source of the energy emitted by the stars?

8. Why is our galaxy believed to be lens-shaped?

9. What warrant have we for accepting the statements of reputable astronomers regarding the nature and extent of our galaxy?

10. Contrast the ancient conception of the stars with that of the modern astronomer.

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CHAPTER FIVE

The Study of Nebulae Has Expanded Man's Ideas of Space

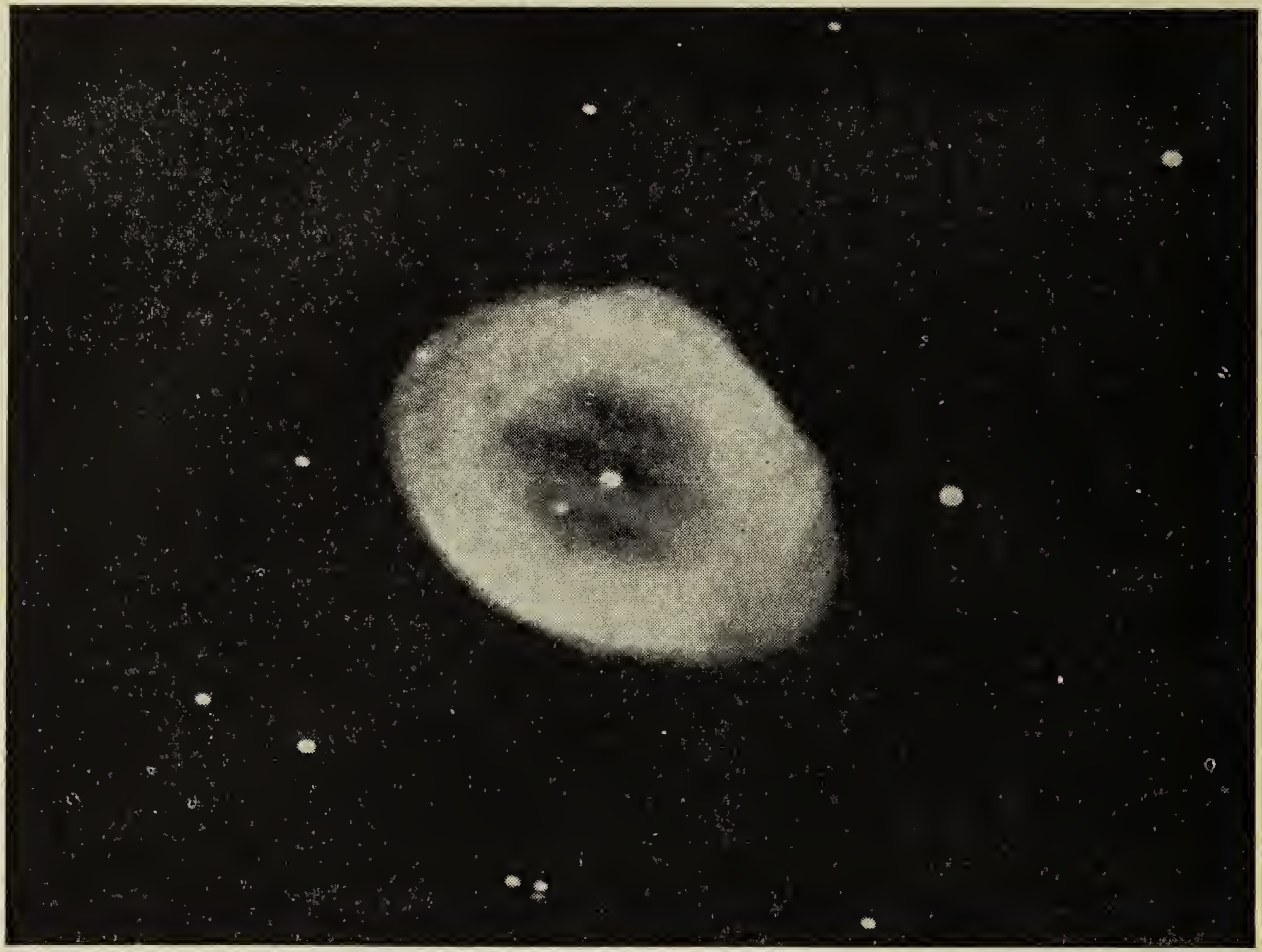
There Are Many Nebulae within Our Own Galaxy. In the early days of astronomical study, vast aggregates of stars, so far away as to have a fuzzy appearance, were thought to be nebulous clusters. The invention and improvement of the telescope, however, have corrected this erroneous conception, and astronomers know them today for what they really are—huge clusters of stars. In addition to these clusters there are in space great tenuous masses of cosmic dust which in many cases have no semblance of form and are very remotely, if at all, related to the stars.

Many of these nebulae lie within our own galaxy. They appear to be enormous in extent and, as one would expect, have no sharply defined limits. Until recently, practically all these nebular bodies known to be within our own stellar system were in the region of the Milky Way. Recently, however, Dr. Shapley of the Harvard Observatory has announced the discovery of a vast sprawling cloud of cosmic dust near the north pole of our galaxy which tends to obscure and redden the light from the stars in that region. The supposed greater frequency of nebulae in the Milky Way, then, may be real, or it may be due to the better illumination afforded by the numerous stars in that part of the sky. Indeed, it may be that nebulae are just relatively denser areas in the very tenuous matter that seems to pervade interstellar space in general.

This interstellar material is so rarefied that there may be but an atom or so per 100 cubic centimeters of space. At sea level there are about 2,700,000,000,000,000,000,000 molecules of air in a similar volume. There is evidence, too, that this interstellar material is not wholly gaseous. Spectroscopic evidence indicates that much of the interstellar matter must exist similarly as small particles of fine cosmic dust. We may sum up this matter by quoting Abbot:

> Space is no longer to be conceived of as completely empty in those regions not occupied by the individual stars and the bright nebulae. The whole intervening regions are populated by obscuring gases so very rare, it is true, as to be far beyond our best vacuums, but still probably containing about the same mixture of chemical elements that we find in the sun or the earth's crust. Besides these gases astronomers are now generally convinced that there is also in space a very rare dusty haze made up of material particles.[1]

[1] C. G. Abbot, "The Contents of Interstellar Space," *Annual Report, Smithsonian Institution, 1933*, p. 218.



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Ring nebula in Lyra

A planetary type

Returning to the *visible* nebulae within our galaxy, we find that some of them are believed to be luminous because they are great gaseous envelopes which surround a more or less well-defined star at the center. These are called *planetary* nebulae. Others shine, but do not seem to be attached to any particular star or stars. These are called *diffuse* nebulae. They have no sharp outline but fade imperceptibly into the background of the sky. Both kinds of nebulae are believed to be illuminated by the engulfed or the surrounding stars.

Then there are great *dark* nebulae, which may be of the same character as the others already discussed, but too far from a luminous body to be made visible. If the cloud were deep and extensive, it might cut off the light of stars in the rear, and in this way appear as a hole among the stars. When Herschel first picked up one of these dark spots with his telescope, he is said to have exclaimed, "Mein Gott, da ist ein Loch im Himmel!" ("My God, there is a hole in the heavens!") One of these large dark spots in the sky in the region of Sagittarius has been dubbed the Coalsack.

Mount Wilson Observatory

Canes Venatici

A spiral nebula of the planetary type

In passing we cannot refrain from mentioning a theory advanced by Dr. Harlan T. Stetson as to the possible effect of these nebular clouds. It must be taken, however, as a theory and not as something the truth of which has been established. He believes it quite possible that thin nebular clouds drifting through interstellar space sometimes envelop a star and thus materially cut down the amount of heat and light emitted from that star. It is obvious that this condition would affect greatly the temperature of any adjacent body depending upon that star for its heat.

Stetson sets forth the idea that the sweeping climatic changes which marked the advance of great glaciers on the earth may have been caused by enormous cosmic clouds of nebulous matter engulfing the sun as they drifted through space. Being denser in some portions than others, the clouds would thus permit intermittent periods of warmer and colder climatic conditions on the earth. In this way the glacial and interglacial periods could be explained. Some geologists believe that we are just now slowly emerging from a glacial period. Stetson believes there is evidence in the sun's corona, for instance, to

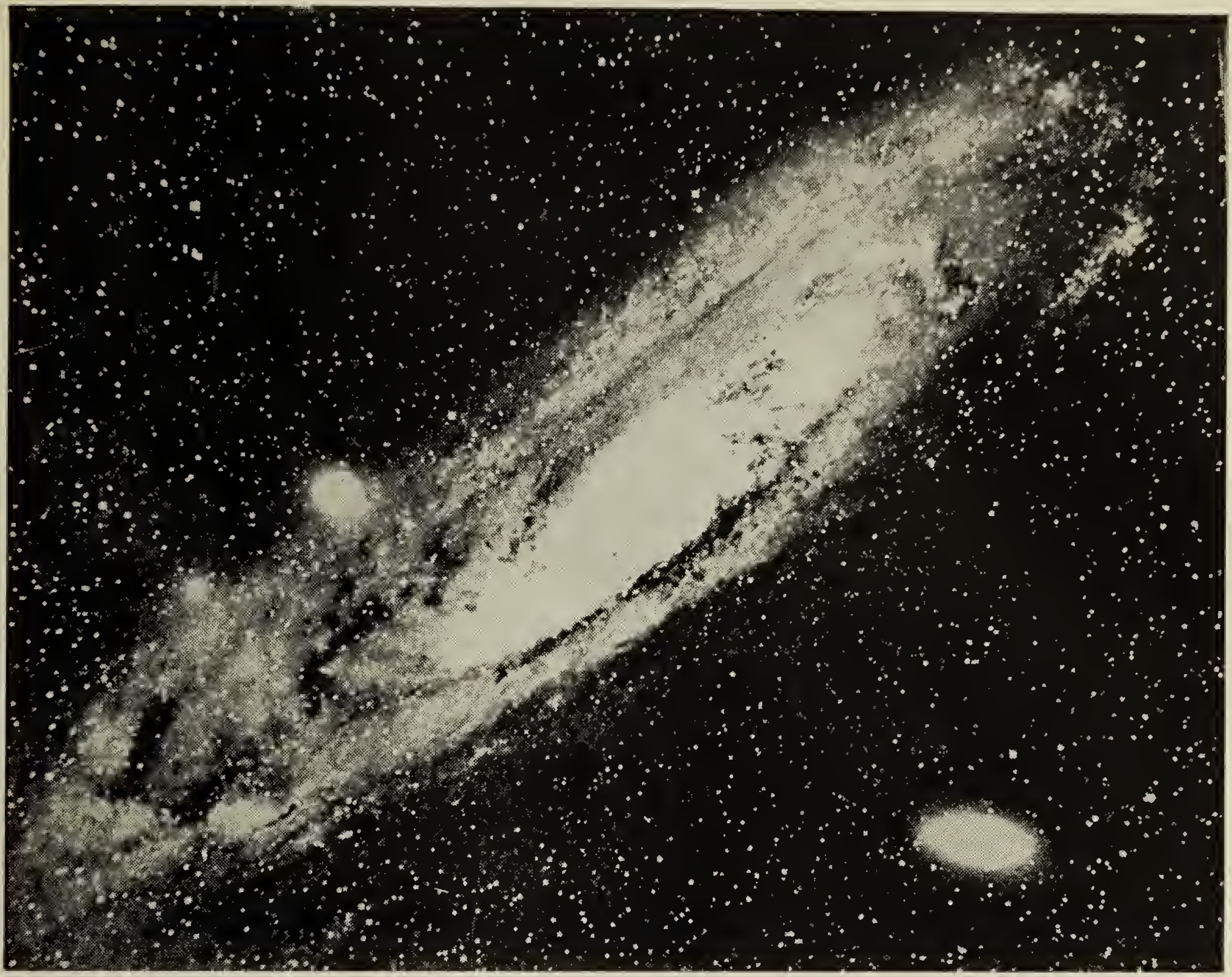
Mount Wilson Observatory

The dark nebula in Sagittarius

support the supposition that the sun is slowly issuing from the tenuous tail end of one of these nebular clouds. If this view be correct, imagination alone can speculate as to the future. The sun might emerge into clear cosmic skies, and warm climates prevail again all the way to the poles. On the other hand, the sun might in time become engulfed again in nebular matter, and a new ice age be initiated. There are, however, other equally plausible theories concerning the cause of the ice ages.

There Are Extragalactic Nebulae. The nebular bodies we have been talking about up to this point are all within our own galaxy, even though some of them are thousands of light-years away. Now, however, we must prepare to stretch our imagination to even greater distances, because far out beyond the limits of our own system of stars lie nebulae and cloudlike forms of amazing import. We shall begin with the best known of these celestial bodies.

High up in the northern sky on an autumn night there appears to the eye of the observer, unaided by camera or telescope, a fuzzy, tiny patch of light which was formerly considered to be a faint star. It is called the nebula in Andromeda, and its presence has been known for centuries. The Persian



Yerkes Observatory

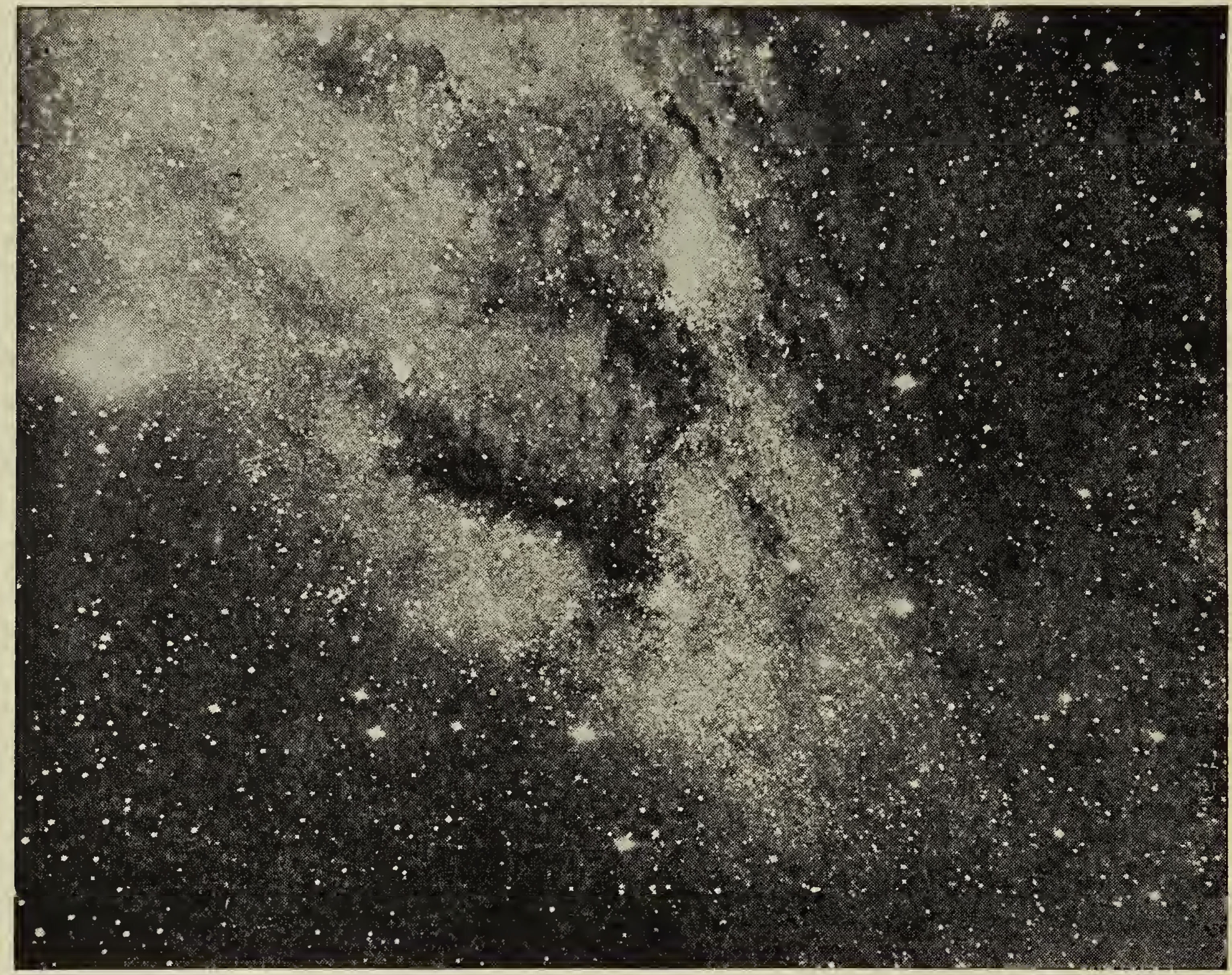
Giant nebula in Andromeda

Note its spiral form

astronomer al-Sufi was aware of its existence as early as the tenth century. This is the only extragalactic nebula that can be seen in the Northern Hemisphere without a telescope. The true character of this nebula and thousands of similar ones, subsequently discovered, would never have been conjectured had it not been for the long-range telescope supplemented by the camera and the spectroscope.

In 1888, eight years after photography had been first employed in the study of the stars, two scientists, by making a three-hour exposure with a twenty-inch reflector, were able to determine the spiral form of the Great Nebula in Andromeda. Later study with more powerful telescopes has revealed the nebula in Andromeda to be not only a giant spiral nebula but one of the most magnificent and sublimely beautiful objects in all the heavens.

Not all these extragalactic nebulae, however, are spiral in form. They may be globular, ellipsoidal, or spindle-shaped. Their total number is very great. It is estimated that about one hundred million of these objects are within the



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Photograph of outer portion of the nebula in Andromeda, showing distinct stars

range of the Mount-Wilson reflector. Just what the new 200-inch telescope, now under construction, will reveal when completed is a matter of conjecture. It seems reasonable to suppose, however, that many millions more of these extragalactic bodies will be brought into view.

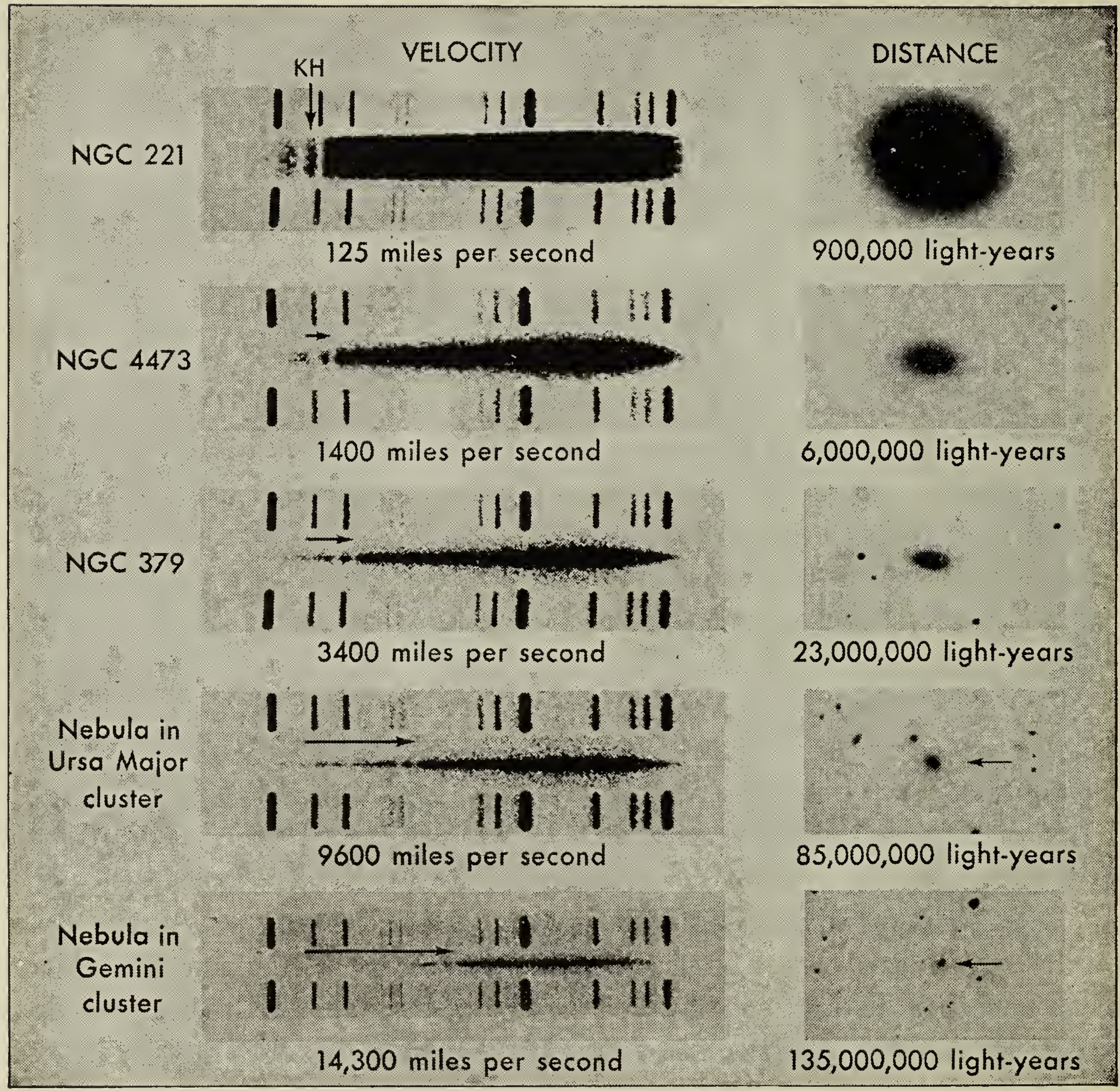
As has been previously noted, these nebulous-appearing bodies are so distant that it is difficult to determine their true character. But after their discovery, speculation as to their nature began. Could it be that all these remote bodies are really assemblages of stars so far away that their light in winging its way to the earth blends together to produce a misty, cloudlike effect? For some of them the answer has been given. Hubble of the Mount Wilson Observatory recently, by prolonged photographic exposure and by concentration of his attention upon the outer portions of some of the spiral arms included in the Great Nebula in Andromeda, has succeeded in resolving them into distinct stars. Even smaller merging patches of light indicating star clusters similar to those in our own galaxy have been made out. Subsequently stars in the arms of other extragalactic nebulae have been detected.

Consequently astronomers now feel assured that there are not only stars beyond our galaxy, but far out in the remote reaches of space—there are not a few but millions of galaxies—"island universes," as Sir William Herschel called them. The stars comprising most of these are arranged in great spirals that go rolling through the heavens like giant pin wheels. Some of them present a flat side to us, some are seen edgewise, while still others exhibit the planes of their long axis at various angles. When seen edgewise, they resemble a giant lens-shaped body similar to the form that our universe is believed to take. Can it be, then, that our galaxy itself is but one of these spiral-like aggregates of stars, and that a person standing on a body in the extragalactic Andromeda and viewing our own stellar system with a hundred-inch reflector would see but a spiral nebula similar to hundreds of others that might be seen out in the sky in all directions? It now seems probable that this is true, and that our magnificent system of stars is but one of a great, common "herd" of galaxies that go moving along through space, to what port or to what destiny no one knows.

The distance to these extragalactic nebulae is almost staggering. For instance, the great spiral in Andromeda is estimated to be almost 1,000,000 light-years away. The flying beams of light that come to us tonight from this magnificent celestial body were yet in mid-course when Pithecanthropus was still lording it over the rest of creation.

Extragalactic Nebulae Are in Motion and Are Moving at Various Rates of Speed. These giant spirals are not believed to be the inactive objects they appear to be out in the heavens. Instead, they seem to have tremendous velocities in two directions, one rotational and the other linear.

Most of the spirals have knotlike patches appearing in their arms. These may be great nebulous clouds or aggregates of stars. Astronomers hit upon the idea of studying these knots to determine whether or not the spirals are rotating like our own galaxy. A series of photographs taken about ten years apart indicate that all the stars are revolving about their common center of mass. More recently this conclusion has been further confirmed by studying certain of these nebulae which are inclined in an edgewise position with reference to the earth. The Doppler effect denotes rapid axial rotation. It has been estimated that, although the nebula in Andromeda is rotating at a rapid rate, its distance around is so great as to require something like 17,000,000 years to make one complete turn. This revolution, it must be remembered, is not like that of a wheel, in which all parts move together, but is more like that of the planetary system as it moves about the sun. The stars nearest the center of the spiral move fastest, while those farther out move more slowly. The solar



Mount Wilson Observatory

Chart showing the velocity and distance of some well-known extragalactic nebulae

Note the shift of the KH line, indicated by the arrow, as speed increases

system, it will be recalled, is so located in our galaxy as to require an estimated 225,000,000 years to make one revolution.

The second type of motion indicated in most of the nebulae is a peculiar one and has led to the theory of an *expanding universe.* With the exception of a few nebulae nearest our own galaxy, spectrograms taken of these extragalactic bodies show a strange shift of the dark lines toward the red end of the spectrum. It is believed that the principal reason why those nearest our galaxy do not show the same shift is that the movement of the solar system within our galaxy, as it rotates, carries the earth toward these near-by extragalactic bodies and thus counteracts the effect of a motion that would otherwise produce a red shift too. On the basis of this evidence the nebulae seem to be receding from us in all directions, and the farther out they are, the faster they move.

The only acceptable hypothesis offered for this strange shift of the spectral lines toward the red end is that advanced by Abbé Lemaître of Belgium. He believes that it indicates an expanding universe, and that the degree of the shift reveals the velocity at which these individual starry systems are speeding outward from the great cosmic center. The only alternative seems to be that this red shift is caused by some other cause as yet undiscovered. As Hubble says, "We may say with confidence that red-shifts are the familiar velocity shifts or else they represent some hitherto unrecognized principle of nature."[1]

Some Reflections Resulting from Man's Increasing Knowledge of the Heavens. No one can consider the great cosmic facts whose portrayal has been attempted in this chapter without wondering about man's individual relation to them. Science has often given man's self-complacency a rude shock. In this respect no one has dealt more roughly with him than has the astronomer with his unfolding knowledge of the cosmos.

Under the Ptolemaic system the earth was the center of the universe, and all the other heavenly bodies made revolutionary obeisance to it. But, beginning with Copernicus, men imbued with the modern scientific spirit began to investigate the heavens. They substituted carefully tested knowledge for circumscribed and narrowly conceived hopes. They advanced the idea, and later proved it, that the sun and not the earth is the center of our system. Moreover, they made the earth a mere pygmy among the planets. This established fact gave man's anthropocentric pride a rude jar. Then the long-range telescopes began to bring in their disconcerting revelations. Not content with ignominiously subordinating the earth, they next attacked the sun. It too was relegated to the state of the mediocre. The astronomer has said that there are literally millions of suns that are bigger, hotter, and brighter than ours. Indeed, our sun is but a declining star, slated soon perhaps, as the years of star life go, for old age, darkness, and oblivion. In our galaxy alone there are something like two hundred billion suns, and the diameter of our galaxy is so great that it takes a light ray one hundred thousand years to dart across it. Man may now begin to wonder whether he is of any consequence at all. Then came the huge reflectors of later days that pick up whole universes of stars at the extreme point of their range, perhaps a billion light-years away. Even then there is no indication at all that space has even begun to be traversed. The colossal spaces sighted and the gigantic systems of stars seen may be not even a beginning in the tracing of the extent and character of the whole cosmos. Now man is thoroughly humbled and sometimes troubled. The former unquestioned faith in man's importance and destiny is often called before the bar of reason to see if it has any validity whatever. In the face of these great cosmic revelations, he feels, as Dr. Millikan has recently expressed it, like an "infinitesimal mite on a speck of a world."

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[1] Edwin P. Hubble, "Our Sample of the Universe," *Scientific Monthly*, Vol. 45, p. 486. (1937)

Still the picture need not be disconcerting. For, although the estimate of man's relative importance as an individual in this colossal cosmos has shrunk tremendously (and of this there can be no question), nevertheless the achievement of his intellect must command his own profound respect. Any being that can make a telescope to peer a billion miles out into space and can plan another to explore thirty times the celestial volume now visible; that can perfect a thermocouple to measure the radiant energy from stars thousands of light-years away; that can devise a spectroscope to reveal what stars hundreds of thousands of light-years away are made of and in what direction they are going and how fast, certainly is no ordinary organism. On the contrary, he must possess a superb mind.

So, while man has had to revise his estimate of his own relative importance in the universe, he has no reason to be demoralized in his thinking. Indeed, almost every important scientific discovery of the past or the present has necessitated a revision of man's ideas. This always has been so, and it always will be. What informed people must do in the light of new knowledge is to reconstruct their philosophies in conformity with scientifically determined facts—not theories necessarily, but facts. Men who do this will realize not only a higher type of faith in the universe, but one that will bring them a larger measure of hope and fortitude in the face of human experiences and responsibilities.

Questions for Study

1. In what ways do the galactic nebulae and the extragalactic nebulae differ?
2. How have the astronomer's ideas regarding the nature of interstellar space changed?
3. How does the astronomer detect either linear or rotational movement in extragalactic bodies?
4. How has the discovery and knowledge of extragalactic nebulae affected man's idea of the *extent* of space?
5. Why do most astronomers believe that space extends far beyond its known boundaries?
6. What is your conception of the phrase "one's philosophy of life," which we frequently hear today?

7. Can you define your own philosophy of life?

8. What effect does the information contained in a chapter like this have on your philosophy of life?

9. What evidence is found in this chapter to support the idea that truth itself does not change but that man's understanding of truth often does change?

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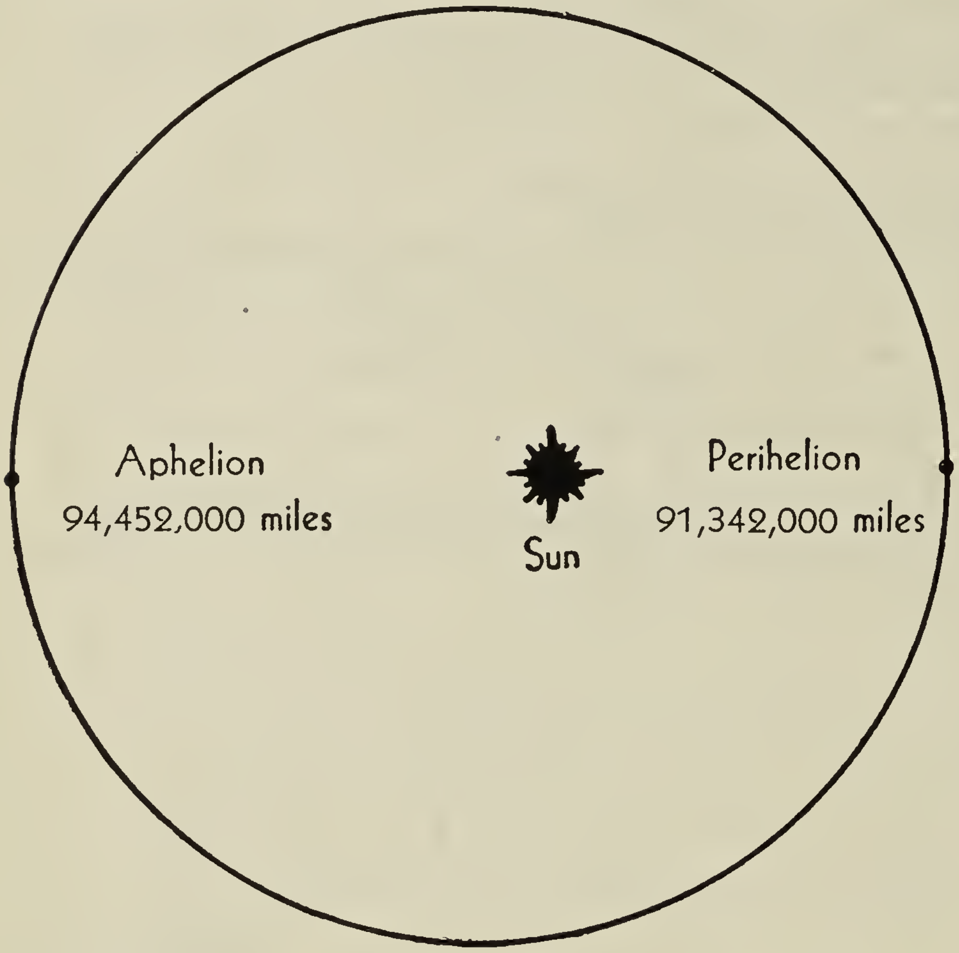
CHAPTER SIX

The Sun Is a Tumultuous Body Whose Radiations Bombard the Earth

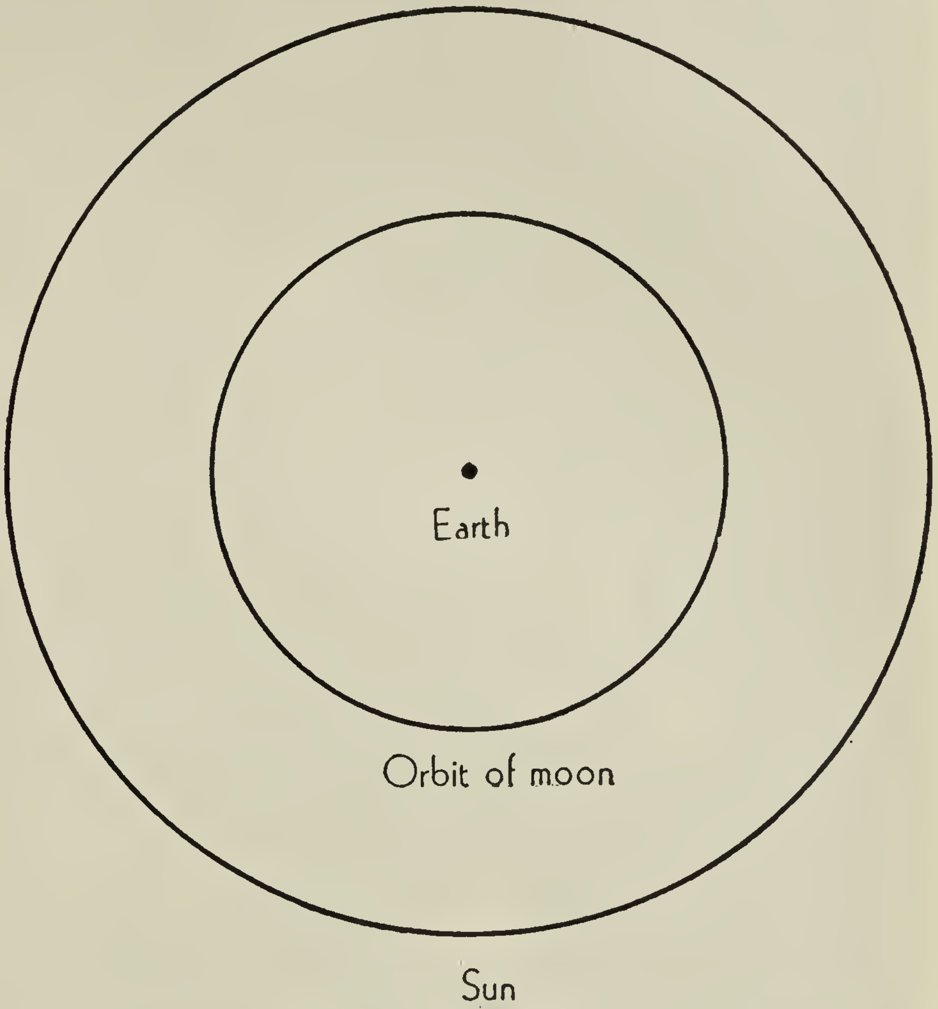
The Sun Is Very Large and Relatively Far from the Earth. Among the stars the sun must be classed as being about average. It is neither brilliant nor dim; it is not extremely hot, nor is it very cool; it is not blue-white, neither is it red. In all respects it must be considered as belonging to the nonillustrious middle class.



A diagram showing the earth at aphelion and perihelion

Yet in comparison with the earth the sun is an object of wonder. Situated about 93,000,000 miles out in the heavens, it holds the earth wholly under its sway. Because of the ellipticity of its orbit, the earth approaches to within about 91,000,000 miles of the sun. It is then said to be in perihelion. In the Northern Hemisphere this occurs during the winter months. During the summer it swings out farther, reaching the extreme distance of about 94,000,000 miles from the sun. When in this position the earth is said to be in aphelion. Because of this change in relative position the sun's heat is about 7 per cent more intense on the earth in January than in July, which tends to produce milder winters in the Northern Hemisphere and colder winters in the Southern Hemisphere.

In size the sun, although not a large star, is, in comparison with the earth, a veritable giant. It has a diameter of 864,000 miles, which is a hundred times greater than that of the earth. If the sun were hollowed out, a million earths could be pressed into this hollow sphere and still leave a little room. To look at it another way: if the earth were at the sun's center, the moon, which is 240,000 miles away, could revolve in its regular orbit about the earth and still be little more than halfway out to the sun's surface. It would take 60,000,000 moons pressed together to equal the volume of the sun. If some celestial Hercules could catch up all the nine planets and press them together into one grand sphere, it would still be a pygmy when set down beside the sun. Indeed, the total mass of this planetary sphere would be but about one seventh of 1 per cent as great as that of the sun.

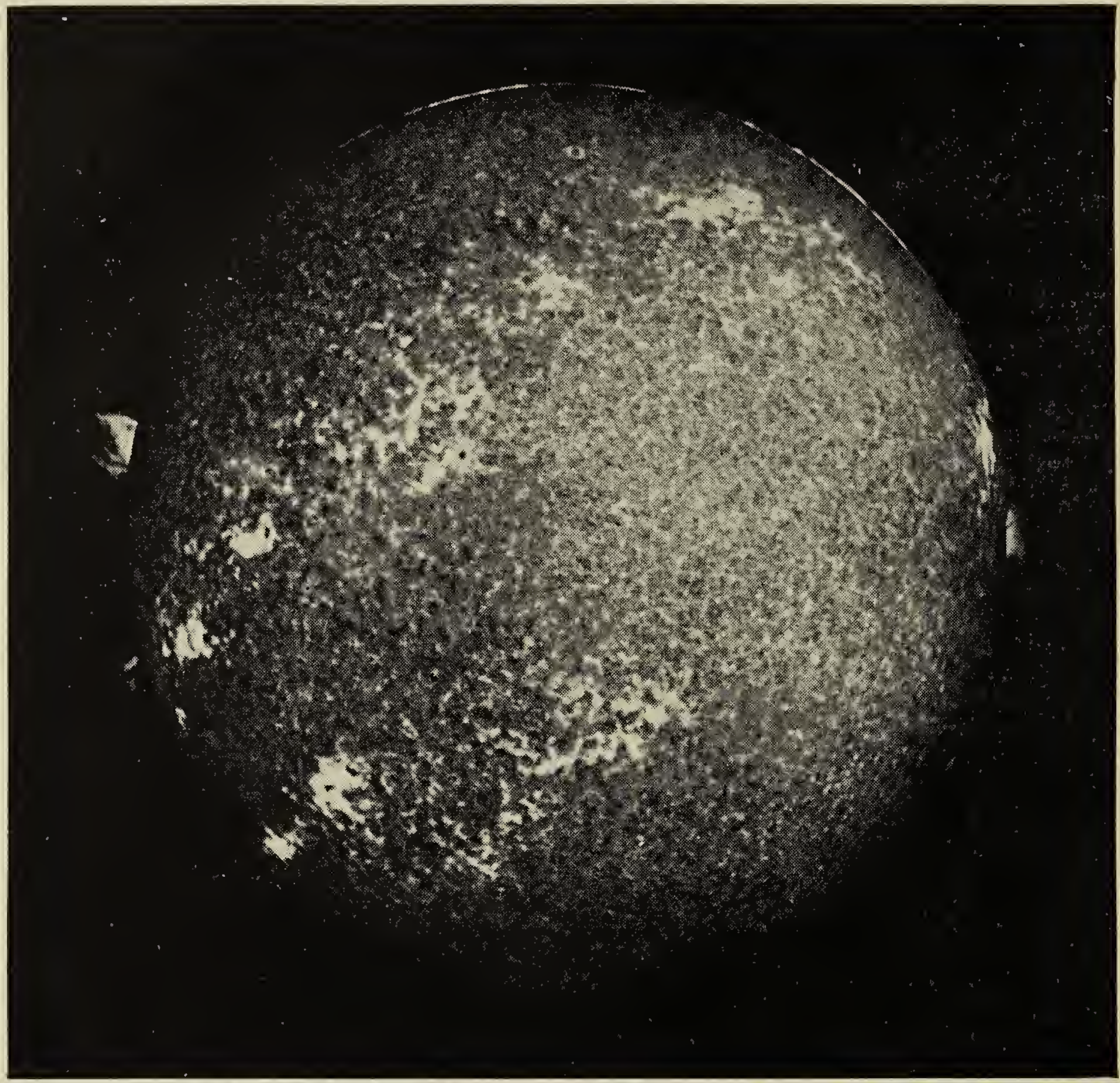


A diagram to illustrate the size of the sun in comparison with that of the earth

The Sun Is Believed to Be a Large Gaseous Body. All observations go to show that the sun is not a solid body like the earth. By observing the movements of sunspots as they pass across its face and also by the use of the spectroscope the rate of the sun's rotation can be determined. It will be remembered that when the source of light is approaching the spectroscope, the Fraunhofer lines are displaced toward the violet end of the spectrum; when it is receding, the lines are shifted toward the red end. Astronomers, then, by examining through the spectroscope the light from one side of the sun as it approaches, and from the other side as it recedes, and computing the difference in terms of line shift, can tell almost exactly how fast it turns upon its axis.

Now, strangely enough, the sun, as noted by the progress of the sunspots, is not turning at all points at the same rate. For instance, sunspots near the equator indicate that the part of the sun's sphere at that point rotates once in 24.6 days; at 35° latitude, in 26.6 days; at 80° latitude, in a period of 35.3 days. This obviously can mean but one thing; that is, that the sun is not a solid body. Parts of a solid sphere could not move at different relative rates.

The high temperatures found in the sun indicate that its mass does not retain the liquid condition. Estimates of the sun's temperature vary some-



Mount Wilson Observatory

A photograph of the sun, May 22, 1916, showing prominences

what. One of the most conservative astronomers places the surface temperature at approximately 6000° C. At the center, because of compression due to the weight of the superimposed layers and to other causes to be considered later, the heat must be extremely great. Astronomers have no way to determine it directly. Careful computations on the basis of the supposed factors involved place it at about 18,000,000° C. It is evident that the average man can no more comprehend the significance of a temperature like that than he can succeed in grasping the meaning of Einstein's conception of space. The hottest white-hot molten metal ever seen in our great blast furnaces would look dark by contrast if placed beside a substance having such a temperature. Under these conditions, then, the sun could exist in no other state than that of a gas.

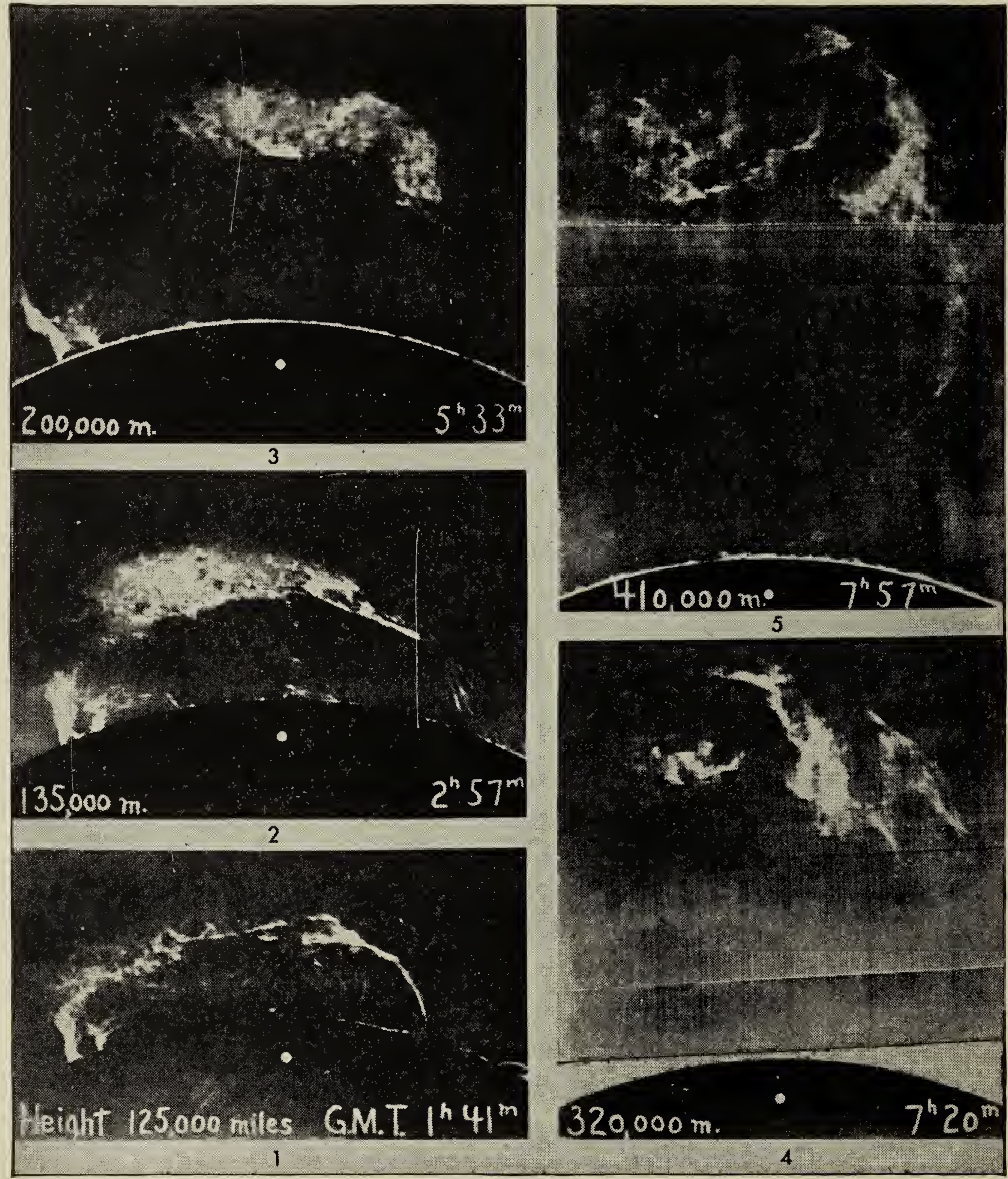
It takes no superimagination to portray something of the appearance the sun would present if one could approach close enough to inspect it. Instead of the benign, more or less quiescent body which we at a distance of 93,000,000 miles unconsciously picture, it must be a seething, raging monster. With all its elements disrupted into gas, great vapor storms must sweep over it. The lighter incandescent gases must be driven far out into space with terrific speed and force. The denser metallic gases would be extruded too, but not so far, owing to their weight. This would produce about the denser part of the stormy sphere a great veil-like layer of hot gases and vapors. This veil is called the *chromosphere* because of its scarlet color. It is estimated to be from 5000 to 10,000 miles in depth—"a 'sea' of red, tumultuous fire," as McCabe vividly describes it.

The more tenuous outer part of the chromosphere is composed chiefly of the lighter gases hydrogen and helium. From the chromosphere great fiery prominences are driven out by some prodigious internal force. These lurid tongues sometimes shoot out to the enormous length of 500,000 miles, or twice the distance from the earth to the moon. Once during a solar eclipse, when they could be observed best, they were hurled up at a speed of approximately 1,500,000 miles per hour. One can but feebly imagine the terrific expulsive force that must lie behind such a spectacle.

Outside the chromosphere and stretching beyond for a million miles or more into space on every side is a soft, silvery-looking light. This light extends up in an irregular and beautiful pattern called the sun's *corona*. Whether it is a sort of atmosphere has not yet been determined. Some prefer to regard the corona as an effect produced by reflected sunlight. The reflecting material is believed by some to be a great cosmic cloud of electronic nature that surrounds the sun. The corona forms a pearly-appearing, outer envelope and is the most impressive feature of the total solar eclipse.

Since the sun is in a gaseous state, its mass is much lower than its volume would lead one to expect. Its volume is over 1,000,000 times that of the earth, but its mass is but 333,000 times as great.

The Sun Is Composed of Elements Many of Which Are Common to the Earth. No information from the sun has been given us by the spectroscope with greater positiveness than that regarding its chemical composition. Since the spectroscope is their informant, astronomers have no way of knowing specifically what elements are found deep down within the sun's mass. The light messages received are restricted to the luminous solar surface and the cooler absorbing gases in the sun's atmosphere. Dr. Russell of Princeton University estimates on the basis of this information that the solar atmosphere


200,000 m.
5h 33m
3
135,000 m.
2h 57m
2
Height 125,000 miles
G.M.T. 1h 41m
1
410,000 m.
7h 57m
5
320,000 m.
7h 20m
4

Yerkes Observatory

Solar prominences being shot out from the sun at tremendous speed

is composed largely of hydrogen, intermixed with some helium and oxygen. The whole is pervaded by metallic vapors produced by the intensely heated solar mass below.

Dr. Russell has computed the tons of each metal[1] found in the atmosphere above each square mile of the sun's surface as follows:[2]

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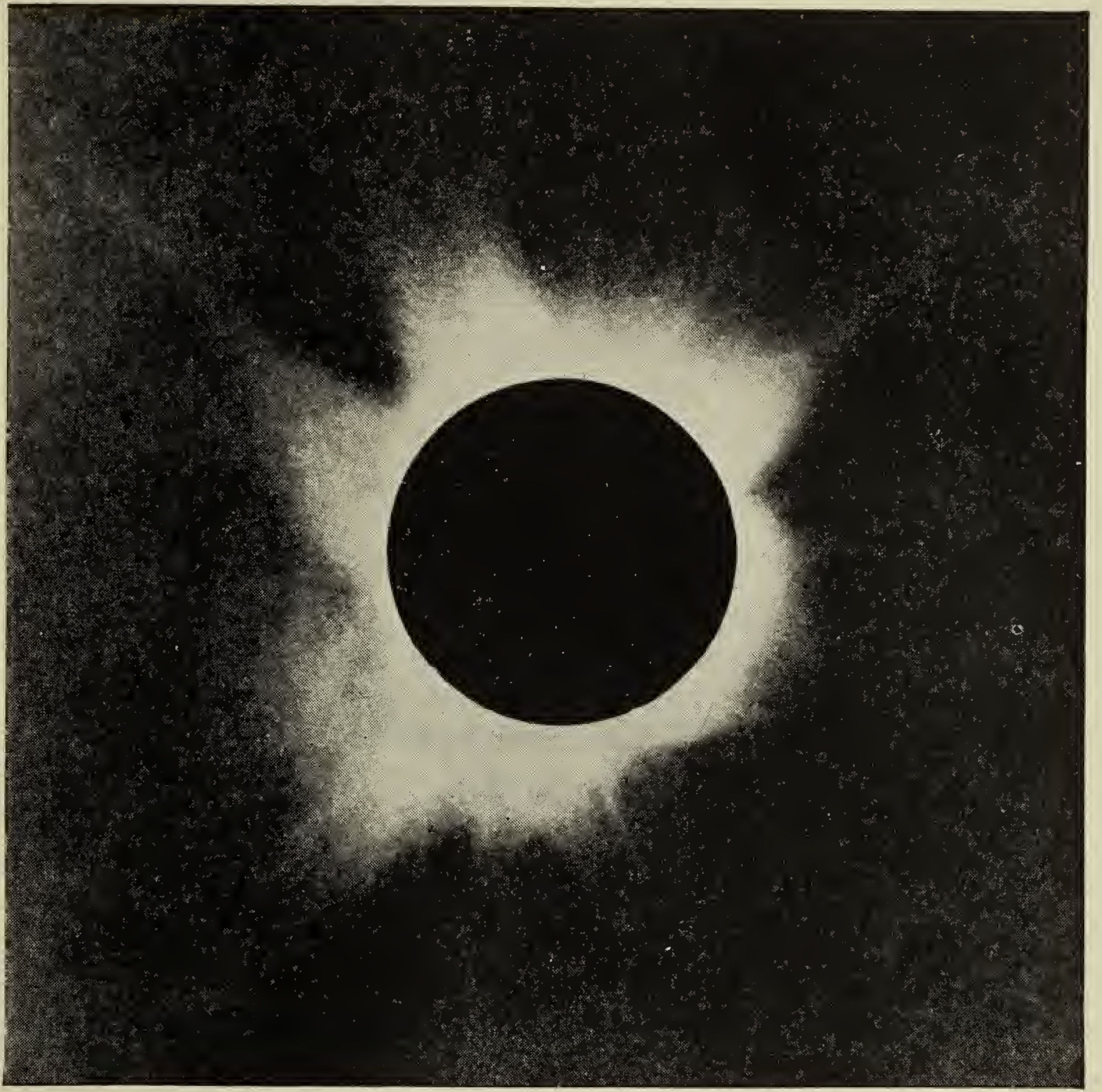
[1] Silicon is included because it behaves spectroscopically like a metal.

[2] *Annual Report, Smithsonian Institution, 1931*, p. 212.



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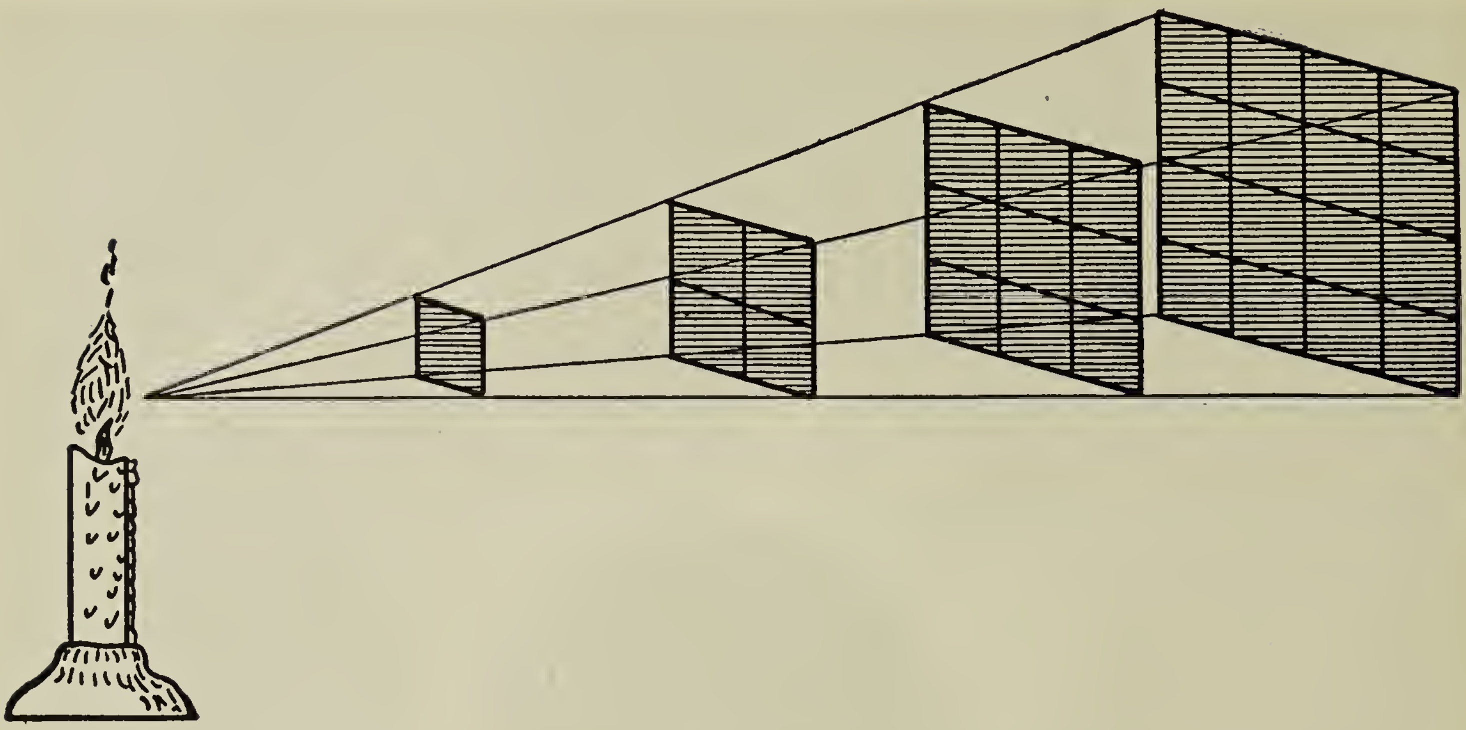
Corona of the sun, taken near sunspot maximum, January 8, 1937

Element	Tons	Element	Tons
Magnesium	350	Cobalt	6
Iron	250	Chromium	6
Silicon	150	Titanium	2
Sodium	100	Vanadium	1.5
Potassium	50	Copper	1.5
Calcium	50	Zinc	1
Aluminum	15	All others	0.2
Nickel	15	Total	1008.2
Manganese	10		

These figures, to be sure, must be accepted with some reservation, as Dr. Russell explains. It is now generally believed probable that every element



Intensity of light varies inversely as the square of the distance from its source

found in the sun may also be found on the earth. The Smithsonian Institution reports at least sixty-one elements considered to be common to both bodies.

The Sun Emits Enormous Amounts of Energy. The sun is shooting energy out into space at a tremendous rate. This energy is in the form of radiations and is emitted in all directions from the solar body. Consequently the part of the radiation that strikes the earth is but a minute fraction of the total amount projected into space. We have previously stated that the intensity of light varies inversely as the square of the distance from its source. This is due to the fact that a beam of light spreads out over more surface the farther it travels. Because of this property of light, the total energy that reaches the earth from the sun is estimated to be but one two-billionth of the total energy emitted.

Since half the sun's radiation is absorbed by the air, we might conclude at first glance that such a small fractional part when sent out over the long journey of 93,000,000 miles to the earth and when spread thinly over almost half the earth's surface must surely be inconsequential in its effect. How wrong such a conclusion would be we all know; for, despite all this thinning out and reduction in intensity of the sun's rays, the energy that finally reaches the earth is astonishing. The Smithsonian Institution has been measuring the intensity of solar radiation at Washington, D. C., for many years. By taking carefully timed readings with a pyrheliometer the observer can not only measure the heating effects of the sun's radiations from day to day but also compare their relative intensities. He finds the amount of heat to be about 1.938 calories per square centimeter per minute outside the earth's atmosphere. A square centimeter, it will be remembered, is a square slightly less than half an inch on a side, and a calorie, for our purpose, may be considered to be the amount of heat required to raise the temperature of one gram of pure water 1° C. In other words, if all the sun's energy striking one square yard of the earth's surface on a clear day when the sun is straight overhead could be caught and be transformed into electricity, it would furnish enough power to run about six family washing machines or nine electric vacuum cleaners as long as the sun remained in that position. This means that the earth is receiving energy from the sun at the rate of 160,000 horsepower for every man, woman, and child now living. The whole earth receives heat from the sun which if harnessed and put to work would do a total of 230,000,000,000,000 horsepower. This again is a figure beyond our comprehension. A very large electric plant will generate about 100,000 horsepower. When we remember the widely scattered and hence reduced character of the radiation coming to the earth, we are perhaps in a position to form a picture of the terrific energy raging in the sun. Yet there are other stars, such as Rigel, mentioned before, which are thirteen thousand times as bright as our sun.

Most of the Sun's Energy Is Believed to Be Produced by Atomic Changes. Doubtless some of the sun's energy, as we have already found, comes from the compression produced by the contraction of its mass. But Menzel places the outside limit of the sun's age at 10,000,000,000,000 years. Even if it is not so old as that, it is certainly very much older than the 20,000,000 years for which the contraction estimated in Helmholtz's theory would furnish the emitted radiant energy. Consequently it becomes evident that most of its energy must have come from some other source, probably from the synthesis of heavier atoms from hydrogen and other simpler elements, as has been previously noted (see page 42). It will be recalled that this synthesis of helium from hydrogen results in a loss of about $\frac{1}{130}$ of the mass of the hydrogen. In other words, that amount of matter is transformed into energy.

This theory as to the source of the sun's radiations is in accord with Einstein's conception that the mass of an atom under proper conditions may be completely transformed into energy. Moreover, experiments have been performed in the laboratory in which part of the mass of certain atoms has been transformed into energy. For these reasons it seems plausible to astronomers to infer that the sun's radiations find their chief source in subatomic changes.

The Sun Is Believed to Be Slowly Decreasing in Size. If the radiant energy from the sun and other stars does come from subatomic transformations, as is now generally accepted, then the sun by losing energy must be constantly growing smaller. This is precisely the point of view held by most physicists today. In fact, it has been computed that the sun is shooting itself away at the rate of 250,000,000 tons a minute. This means that the sun today has a mass 360,000,000,000 tons less than it had yesterday. To visualize this loss further Jeans states that if mass were flowing away from the sun in the form of 650 streams of water, each the size of Niagara Falls, its loss in mass would then just about equal its present loss through radiation.

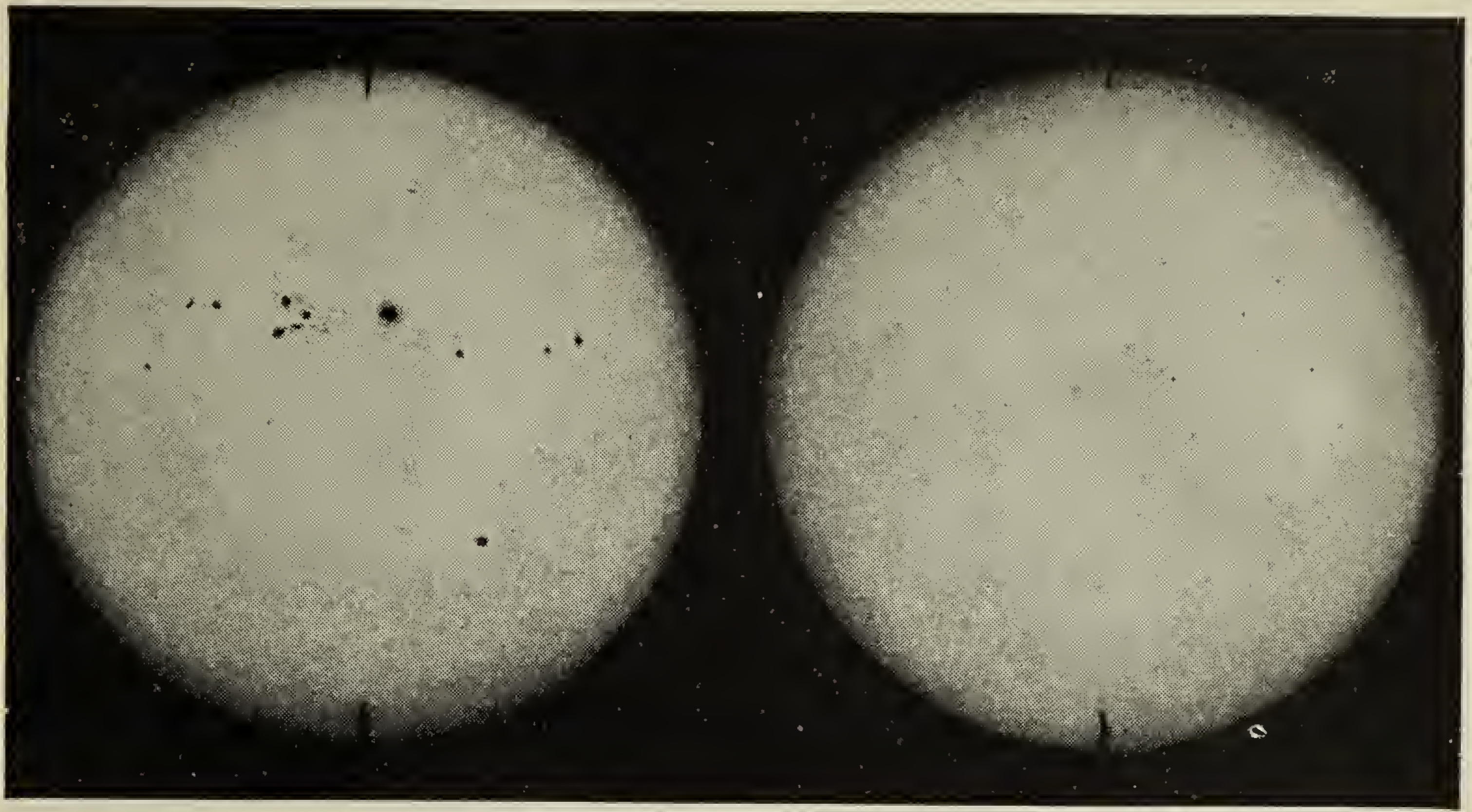
This figure seems very large to us and implies that after a while the sun must shrink up and wholly disappear. That it is losing mass in this way there can be little doubt. Moreover, on a body the size of the earth such a loss would be of disastrous consequence; but in a body the size of the sun a loss of this magnitude is not so serious. Dr. Eddington estimates that if all the sun's mass were converted into energy in this manner, it would suffice to keep the sun radiating energy at its present rate for 15,000,000,000,000 years. Even if the sun's energy is derived in this way, it need cause us no concern as to the future; for millions of generations of men could be born, live to a ripe old age, and die before the diminution in the sun's heat would be perceptible at all to the ordinary man.

Tremendous Disturbances on the Surface of the Sun Appear as Sunspots. As one views the sun through a telescope, it presents a sort of granular, or mottled, effect. On its surface now and then appear darker patches known as sunspots. Study has revealed that these spots are great whirlpools produced by peculiar disturbances in the solar gas. They are dark because they are cooler than the surrounding areas of the sun. Nevertheless, even in this condition, these centers are extremely high in temperature.

Sunspots vary greatly in size. The smallest ones visible are as large as the state of Texas. Occasionally they appear so enormous in area that the whole earth could be dropped into a single one without beginning to touch its boundaries. Indeed, some have been observed whose diameters were estimated to be 40,000 or 50,000 miles and whose areas were several million square miles.

Sunspots were discovered by Galileo, and more or less complete records of their appearance have been kept for something like three centuries. There are times when the spots entirely disappear from vision for several months, and careful study has revealed that they are periodic in their appearance. Schwabe first pointed out the fact in 1843 that the sunspots begin, grow in size and number, and then wane. The period of their cycle, with some irregularity, is about eleven and one-half years.

The behavior of sunspots is peculiar in many ways. One of these is their successional location. At the beginning of the eleven-and-one-half-year



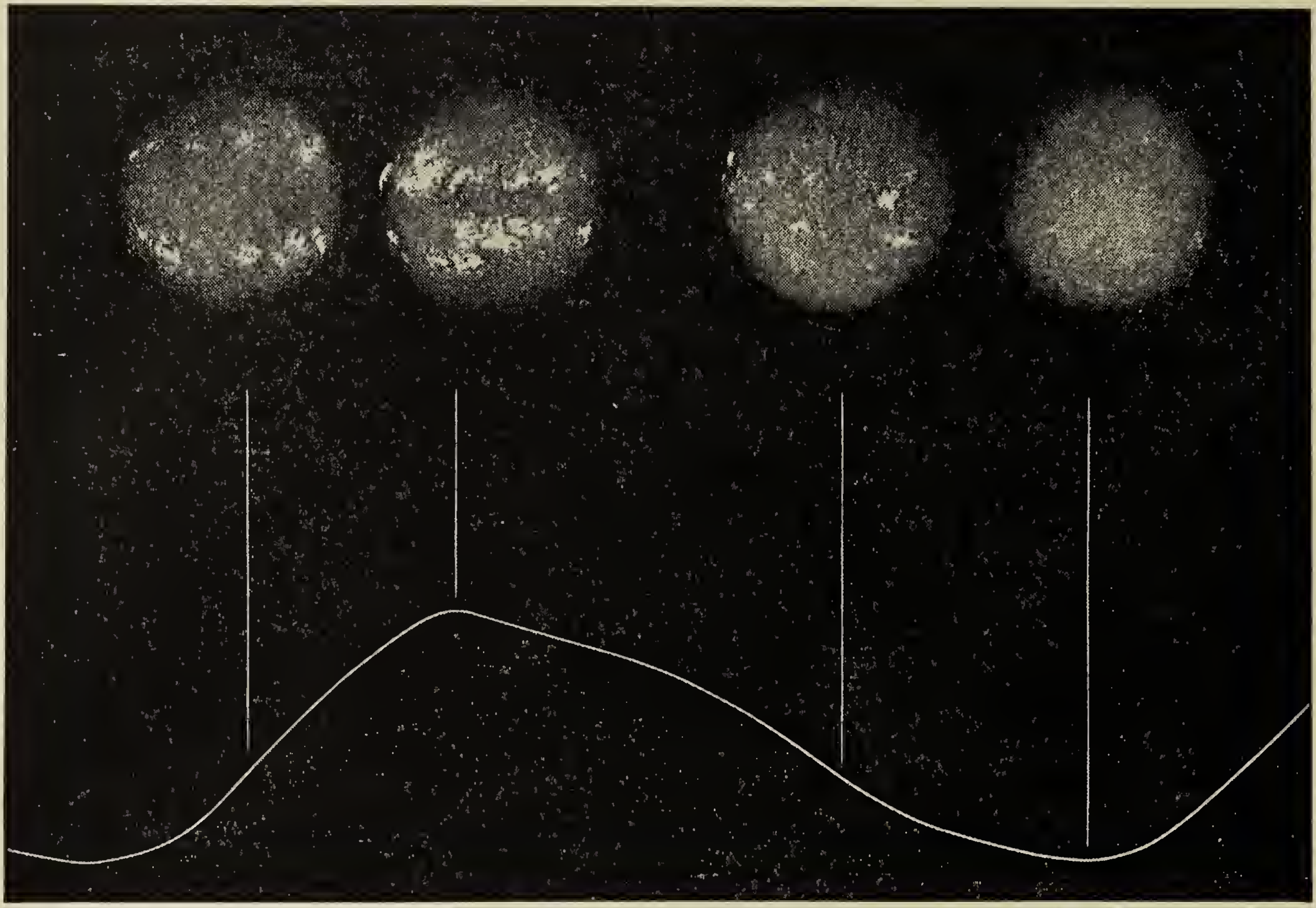
Mount Wilson Observatory

Comparison of direct photographs of the sun at maximum spot activity, November 30, 1929, and at minimum spot activity, June 22, 1931

period they appear at relatively high latitudes—in the neighborhood of from 35° to 40° latitude on either side of the sun's equator. As the cycle progresses, they, with some fluctuation, break out nearer and nearer the equator. At their maximum they occur most frequently at the solar latitude of about 15° in both hemispheres. After the maximum has passed, the sunspots diminish in both size and number and continue to appear at decreasing latitudes. In the end a few scattered spots may be seen at from 2° to 5°. This marks the end of the cycle. By this time, however, a new cycle has been initiated through the appearance of spots again at the higher latitudes.

Sunspots appear to be great raging whirlpools of expanding gas that tend to sweep anything near them into their vortex. Physicists have found that as a gas expands, it cools; for that reason the sunspots are estimated to be about 3500 F degrees cooler than the surrounding areas of the sun. Another characteristic of sunspots is that, like the cyclonic storms on the earth, they whirl in one direction in the Northern Hemisphere and in exactly the opposite direction in the Southern Hemisphere.

Sunspots are now known to act as huge magnetic poles. In 1896 Zeeman discovered that the spectrum made from an electric arc which had been placed between the poles of a magnet had its lines split into two bright lines and several fainter ones which were characteristically arranged. This effect is due to the influence of the magnetic field on the orbits of the electrons of the atoms which form the incandescent arc. After this discovery Dr. Hale



Mount Wilson Observatory

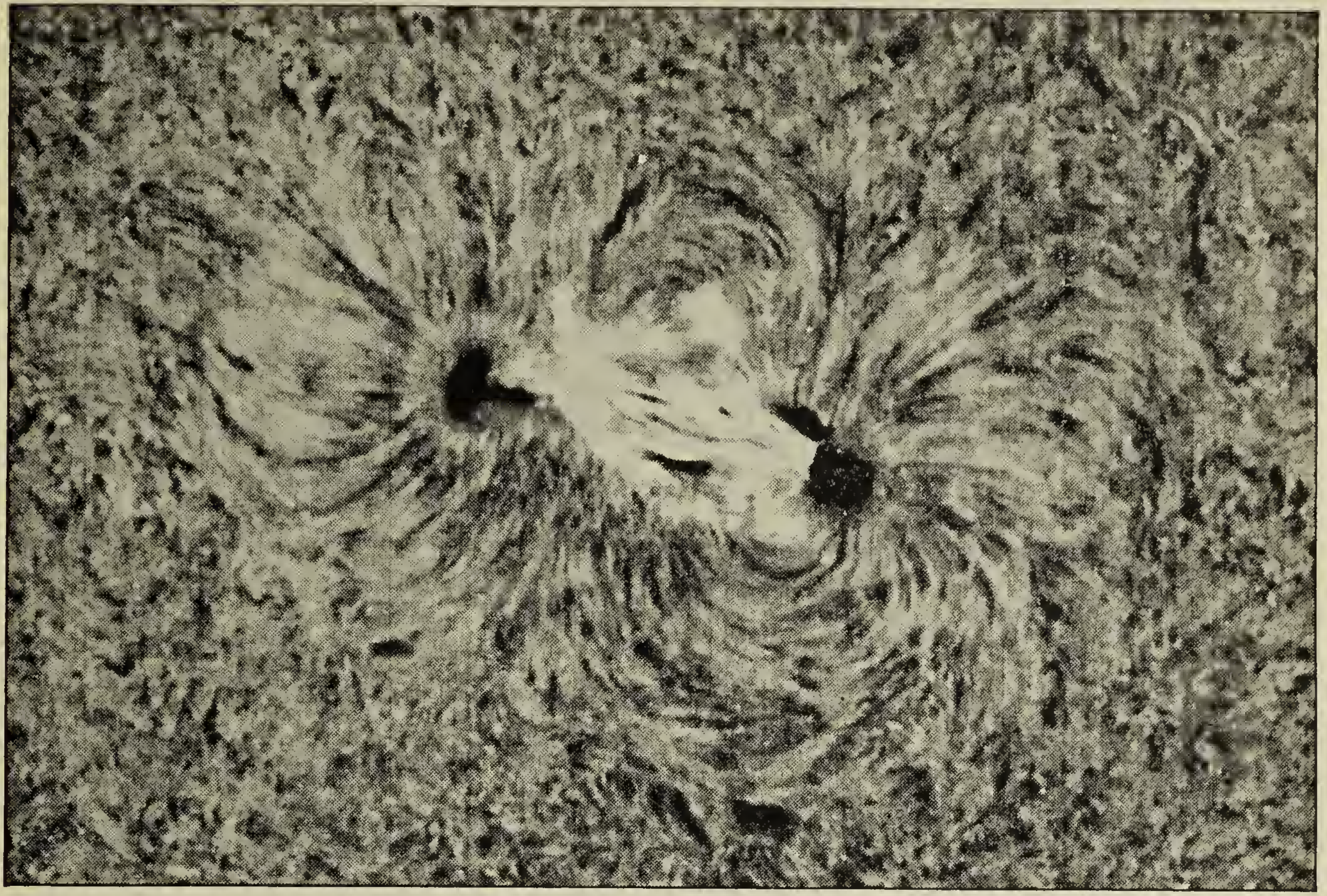
Curve of a sunspot cycle, with four spectroheliographs

The appearance of the sun at different phases of the cycle is shown

of the Mount Wilson Observatory, by studying the characteristics of the light from sunspot fields, was able to determine that these spots were magnetic in nature, and he also ascertained the strength of their fields and their orientation with reference to north and south magnetic poles. In this way the magnetic field of some sunspots has been found to be 20,000 times as powerful as that of the earth. Imagine trying to navigate a ship by compass or to tune in on a radio program if such a raging magnetic storm should occur on the earth as must prevail in the neighborhood of these sunspots.

As a rule, sunspots are not long-lived, but sometimes very large spots will persist for days and even months, surviving through several rotations of the sun on its axis. The spot of longest record appeared in 1840. It survived for a period of eighteen months.

Sunspots Influence the Earth. Perhaps the most interesting feature of sunspots is their effect upon the earth. At first it did not occur to scientists that spots on the surface of the sun 93,000,000 miles away could very profoundly affect conditions on the earth. But subsequent study has revealed a different state of affairs; and new evidence to support this view is piling up all the time.



Mount Wilson Observatory

A bipolar sunspot, August 30, 1924

Note the close resemblance to a magnetic field

Sunspots are believed to influence weather cycles. It has been concluded from observations that periods of maximum sunspots are accompanied, somewhat closely in point of time, by cooler weather and heavier rainfall on the earth. Extensive records of the sun's intensity seem to show that actually more radiation is sent to the earth at times of maximum sunspot disturbances than when they are at their minimum. But perhaps because of the cooling effect of greater evaporation and the increased cloudiness resulting therefrom, the expected weather conditions are reversed. Douglass of the University of Arizona finds that he can trace the sunspot cycle back for centuries by the character of the annual-growth rings in trees. The rings formed during the times of maximum sunspots are thicker because of more favorable growing conditions.

At the Blue Hill Observatory in Massachusetts it has been found that 40 per cent more snow on the average falls during sunspot maxima than during sunspot minima. Moreover, the North Atlantic has from 10 to 20 per cent more precipitation during years when sunspots are at their height; South America, Africa, India, and Australia also show from 10 to 20 per cent more rainfall; and the arctic and antarctic regions show from two to three times as many icebergs as when there are few sunspots. Kullmer of Syracuse University, on the basis of the solar cycles extending from 1883 to 1913, found 40 per cent more storms passing over the fundamental storm track of North America when sunspots were at their maximum. Should these findings be further extended and verified, the study of sunspots may contribute greatly to long-range weather forecasting in the future.

The northern lights, or aurora borealis, are also much more marked during sunspot maxima. This phenomenon is believed to be caused by electrified particles shot out from the sunspot disturbances. The magnetic field of the earth deflects many of these particles in a curved path toward the magnetic poles. At an elevation of a hundred miles or more they are considered to ionize, or electrify, the atmospheric gases, such as helium, oxygen, and nitrogen, so that the beautiful and varied auroral illumination results. Similar displays are known to be simultaneously produced about the south magnetic pole. Admiral Byrd observed these extensively on his last trip to Antarctica and has vividly described them.

One of the most interesting accompaniments of the maximum sunspot periods, however, is the widespread magnetic storms that sweep over the earth. Vast atmospheric electrical currents are believed to be set up, 60 to 90 miles above the earth, by emanations which sweep down from the sun. The extent and intensity of some of the magnetic storms induced by these electrical currents are almost incredible. In 1859, during such a disturbance, the inductive effect was so great as to generate sufficient current in telegraph lines to make their operation possible without batteries. The one in September, 1941, increased the voltage of an electrical transmission line at Baltimore, Maryland, 5750 volts, or more than fifty times the voltage of the electric-light line that supplies our homes.

There are two principal theories as to how these magnetic storms are produced. One is based on the fact, mentioned in the preceding paragraph, that streams of electrified particles emanate from the turbulent sunspot areas. According to this theory, then, there is a continual "ebb and flow," as Stetson says, "of electric currents in the air above us," as daylight and darkness follow each other.

> Like giant ocean currents they stream from the equator to the pole, changing their course with the changing amount of sunshine and becoming violently disturbed when huge sunspots belch forth and rain corpuscular shrapnel in the earth's direction.[1]

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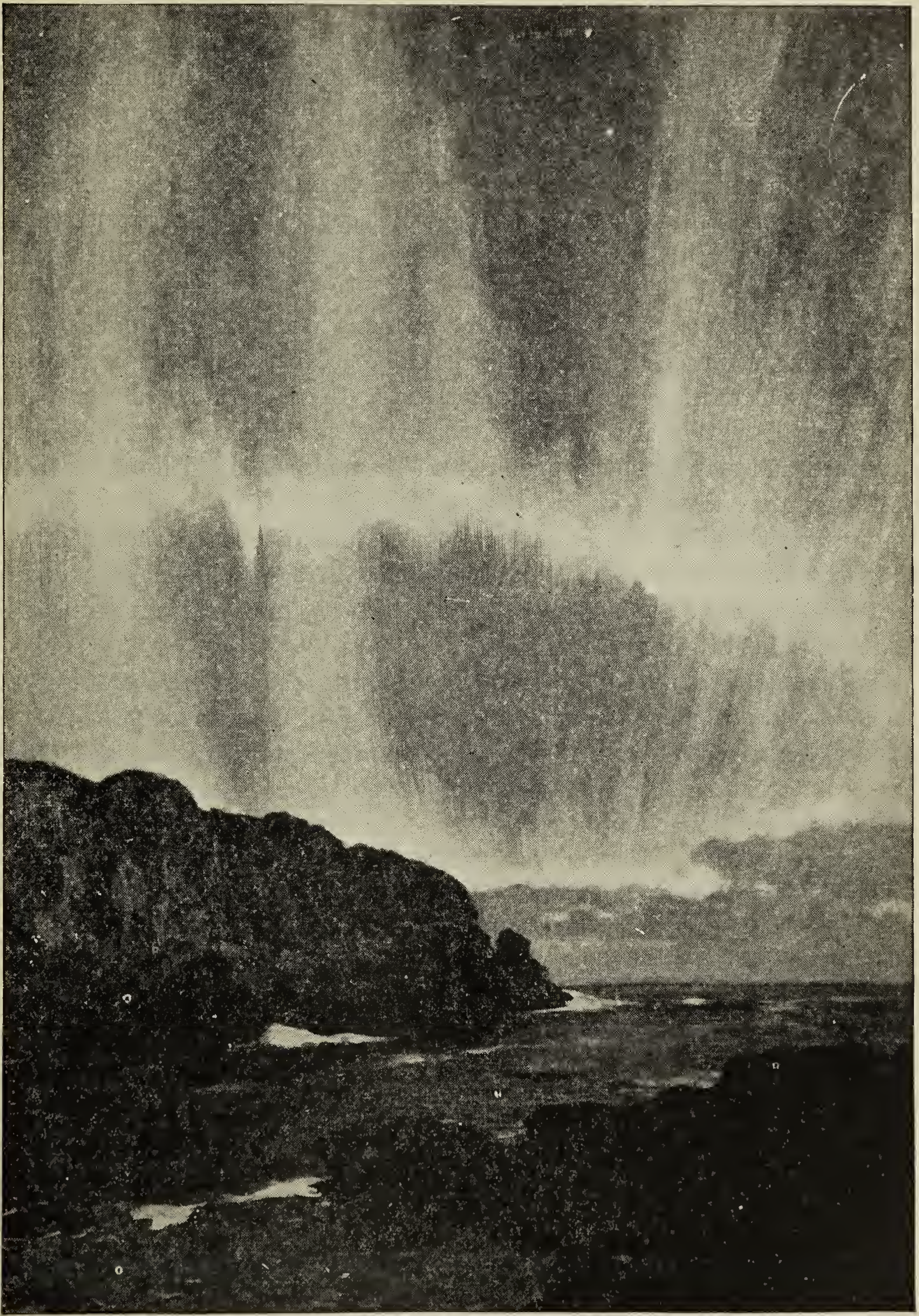
[1] Harlan T. Stetson, *Sunspots and Their Effects*, p. 136. (1937)



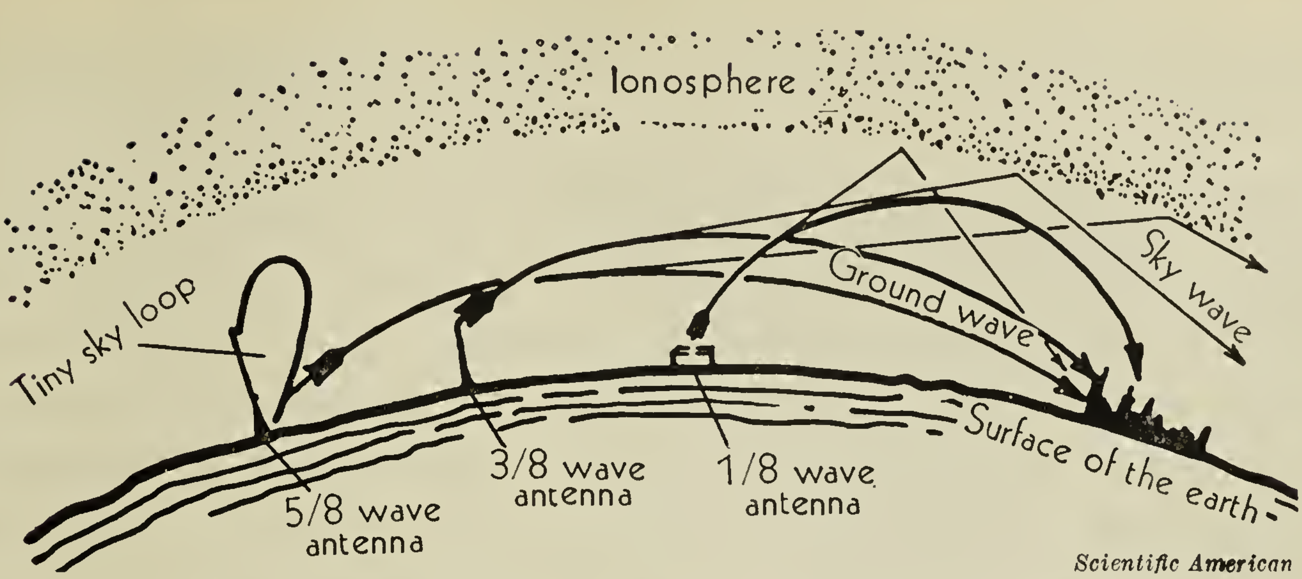
Painting by Howard Russell Butler from the American Museum of Natural History

Aurora borealis as seen from Ogunquit, Maine, August 12, 1919

The second theory proposed is that the magnetic disturbances are caused by the effects of ultraviolet light. With certain exceptions which may be explained theoretically, sunspot periods are known to be accompanied by intensified emanations of ultraviolet rays. These rays are known to ionize atoms of gases with which they collide. The more intense the rays, the greater their ionizing effect on the oxygen and nitrogen molecules of the upper atmosphere, and the more electrons are set free to move under the influence of the earth's magnetic field.

At any rate, from one or the other of these two causes or from both of them acting together electrons are believed to be produced which result in what are sometimes violent magnetic storms. It has been noted that "the delicate little needles of the magnetic observatories flip to and fro, violently disturbed and agitated by happenings on the sun." Very delicate balances have been devised with which to measure the magnetic force that pulls the compass needle north. Measurements of this kind are being taken daily all over the world. In this way it has been found that, on an average, the pull on the magnetic needle is twice as great during years of maximum sunspots as during years of minimum sunspots.

But perhaps the most interesting and at present the most important known effect of sunspots is their disturbance of electrical communication. As far back as the invention of the telegraph, communication by wire and cable has been seriously interfered with during periods of maximum sunspots. This is believed to be due to the action of electrons and particularly to the *ionosphere* (the ionized region of the earth's atmosphere) and changes which take place in it. We have already noted that ultraviolet light tends to knock the electrons off gaseous atoms and ionize them. The layer of upper air in which the solar ultraviolet rays produce this effect is believed to extend all about the earth in the form of a sphere. For this reason it is called the ionosphere. This sphere is found at the level where the air molecules become sufficiently dense to arrest the major part of the ultraviolet rays. In general, as has been previously stated, it may be said to be at a height of about a hundred miles. But, naturally, it is lower and denser immediately below the sun, owing to the increased ultraviolet light, and higher and less dense in atmospheric regions not receiving the direct rays of the sun. Affected by these conditions, this ionized ceiling daily fluctuates up and down as the earth rotates on its axis. Since sunspot periods are also times of stronger ultraviolet emanations, the ionosphere tends to be lower during sunspot maxima and higher during sunspot minima. This influence imposed upon the normal daily effect of the sun's apparent movement around the earth greatly complicates the fluctua-



Radio waves are believed to be deflected by the ionosphere

tion in height of the ionosphere. In fact, this ionized region, in respect to character and height, seems to be very complicated. Sometimes there are apparently two ceilings, one superposed on the other.

The ionosphere is believed to act as a ceiling against which radio waves "strike" and are directed back to the earth, much as light is reflected by a mirror. It is only for this reason that long-distance radio communication can be carried on at all. Were it not for the existence of this ceiling, the radio waves, owing to the curvature of the earth, would "slide" off the earth at a distance of forty or fifty miles from their point of origin, never to return. In other words, radio communication would be limited to the distance that radio waves could pass along the earth's surface horizontally before the curving surface of the earth diverged from their paths.

But with the ionosphere present to reflect them, the waves may not only come back to earth but may be redirected upward from the earth's surface. This up-and-down deflection may take place many times. Imagine an individual standing at one end of a long, narrow hall with a low ceiling. He might, by throwing a rubber ball with sufficient force against the ceiling at a proper angle, cause it to be deflected back to the floor, then bounced to the ceiling again, and so on, alternating between the ceiling and the floor. Ultimately, if originally propelled with sufficient force, the ball would traverse the whole length of the hall. This simple illustration indicates what is thought to take place between the earth and the ionosphere when a singer, for example, broadcasting can hear his voice in a receiving set a fraction of a second after he has begun to sing. "Bouncing" between earth and ionosphere, the radio waves set up by the singer's voice through the microphone are believed to have circumscribed the globe and returned to the point of origin.

At times, owing to a combination of factors not wholly understood, the radio ceiling seems to fluctuate upward or downward very quickly. This is believed to contribute to the "fading" effect often experienced in long-distance radio reception. Fortunately, however, not all wave lengths, apparently, fade at the same time. For this reason transoceanic telephone communication is constantly watched by radio operators, who may switch the wave length used to facilitate the conversation whenever serious fading out begins. Such a change is frequently made without the knowledge of the speaker. This shows how far toward technical perfection radio communication has progressed.

With the growing knowledge relative to the importance of sunspots in electrical communication, companies in this field and other research organizations have instituted an active investigation of this phenomenon. H. W. Wells of the Carnegie Institution, in this way, was able to predict the magnetic storm of September 18, 1941, two days before it occurred. This storm was one of the most violent on record and was accompanied by a magnificent display of northern lights.

Will the Sun's Rays Ever Be Utilized Directly as a Source of Power? This is a question often raised. There would certainly be an abundance of power if the rays could be condensed and utilized. Enough heat falls on a roof 50 by 150 feet to develop, at 30 per cent efficiency, 300 horsepower.

Direct rays of the sun are now employed extensively in the South to heat privately owned water tanks. These solar heaters, so made as to expose a large surface relative to their volume, are set in the roofs of houses. They are well insulated on the sides and set under a glass, instead of a shingled, section of the roof. On hot days it is surprising how rapidly they heat. The water in them often boils. This method of heating water was introduced into California as early as 1913. It was begun in Florida in 1919 and has come into such general use there that late reports show approximately 90 per cent of all new homes in Miami to be equipped with this type of heater. One manufacturer in that city has installed ten thousand of them since 1923. An average temperature of 160° F is promised throughout the year in southern Florida, and a temperature of 205° F has been recorded at the top of a tank.

By the condensation of the rays of the sun on special types of boilers, solar engines have been perfected that pumped water in both California and Egypt. The water pumped in Egypt was used for irrigation purposes. Solar cookers have also been devised.

One of the chief disadvantages of such a power plant, of course, is that it cannot be run at night, and its efficiency is very greatly reduced, if not completely lost, in cloudy weather. As a source of continuous power the units would have to be supplemented by electric generators and ample storage batteries or by pumps that would store water in a reservoir at a higher level.

Recently, owing to the generosity of Dr. Godfrey L. Cabot of Boston, a gift of almost $650,000 has been presented to the Massachusetts Institute of Technology for the purpose of research "on the utilization of solar radiation for the tasks of man." This research is being carried on under the direction of Dr. Hoyt C. Hottel of the institute's staff.

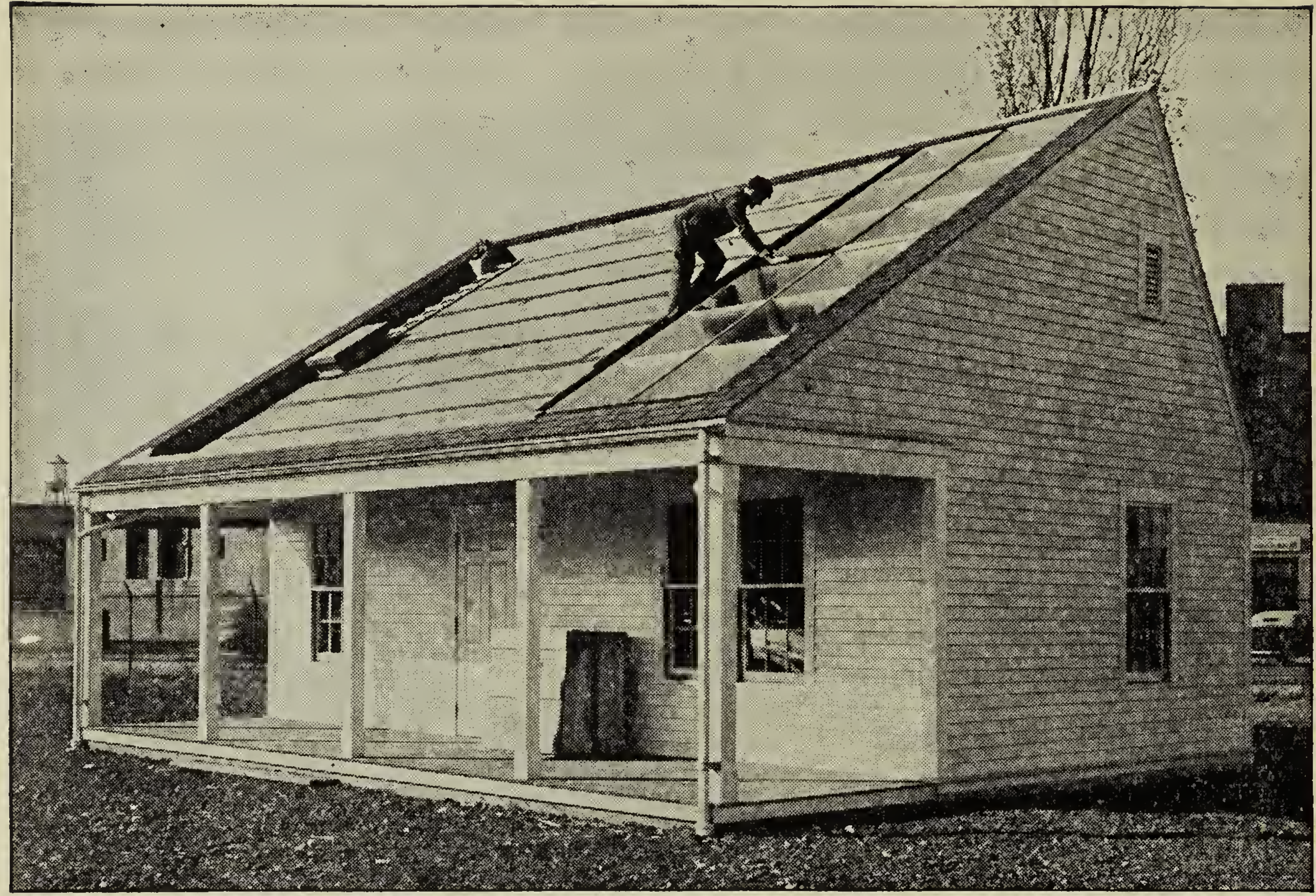
Although several types of energy-collectors, or "heat traps," are to be tried out, first attention is to be given a shallow, boxlike heat-collecting device placed in a recess on the roof of the experimental building. The bottom of the box is a thin sheet of metal painted black to absorb the utmost amount of the solar energy. Firmly fixed to the underside of the black sheet is a system of small thin-walled metal tubes which are heated by contact with the sheet and which in turn heat water as it is circulated through them.

Smithsonian Institution

A solar cooker developed by Dr. Abbot reached an efficiency of 15 per cent

The boxlike heat-collector has a series of several glass covers between which dead-air spaces are arranged. In this way it is possible for the sunlight to pass through the glass into the box, where it is transformed into heat when it strikes the metal sheet. But, because of the non-heat-conducting properties of still air, little of the generated heat can escape through the glass-air cover in the reverse direction. Beneath the box is a layer of mineral wool to prevent the escape of heat in that direction.

After the water has been warmed in the heat-collector, it passes through carefully insulated pipes to the storage tank in the basement. This large, thoroughly insulated storage tank will be used as a source of continuous heat produced by the variable and intermittent energy of the sun. The energy to operate the building's heating system is furnished by the water in this tank. This system consists of a method of forced air circulation so arranged that the flow of air can be either over the hot tank surface in winter or through a



Massachusetts Institute of Technology

House with heat trap

Built by the Massachusetts Institute of Technology for research on the utilization of solar radiation as a source of heat

refrigeration system in the summer. Several methods of operating such a heating system are to be studied at the institute. A sunlight-collector large enough to heat the house directly might be used, thus making necessary only a relatively small storage tank to heat the house at night or during periods of cloudy weather. Or a small collector might be used and heat stored all summer in a tank large enough to hoard an entire winter's supply of heat.

Reports from Russia indicate that engineers in that country also are investigating the possibilities of the sun as a source of heat and industrial power. However, with other sources of power so abundant and relatively cheap, it is not likely that the direct rays of the sun will be employed on a large scale for a long time. Nevertheless, when coal, oil, and timber resources are exhausted, as they bid fair to be, man may have to press his ingenuity to the utmost to devise ways to get heat and power from the sun and perhaps from the ocean tides to carry on the activities of civilization.

Questions for Study

1. Why, do you suppose, did so many primitive peoples worship the sun?

2. How is the sun's radiant energy believed to originate?

3. How has your conception of the intrinsic nature of the sun been affected by your study of the stars and the sun?

4. How is your existence on the earth conditioned by solar radiations?

5. Why does the earth receive, according to estimate, but one two-billionth part of the sun's total radiation?

6. Why do astronomers believe that in the billions of years to come the sun will become a very much cooler and "decrepit" body?

7. Do you believe that the sun's rays will be utilized directly in the future as a source of power on a large scale? Why?

8. What evidence may be marshaled to indicate that the earth's climate for centuries past has been affected by sunspot frequency?

9. How was the magnetic nature of sunspots determined?

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CHAPTER SEVEN

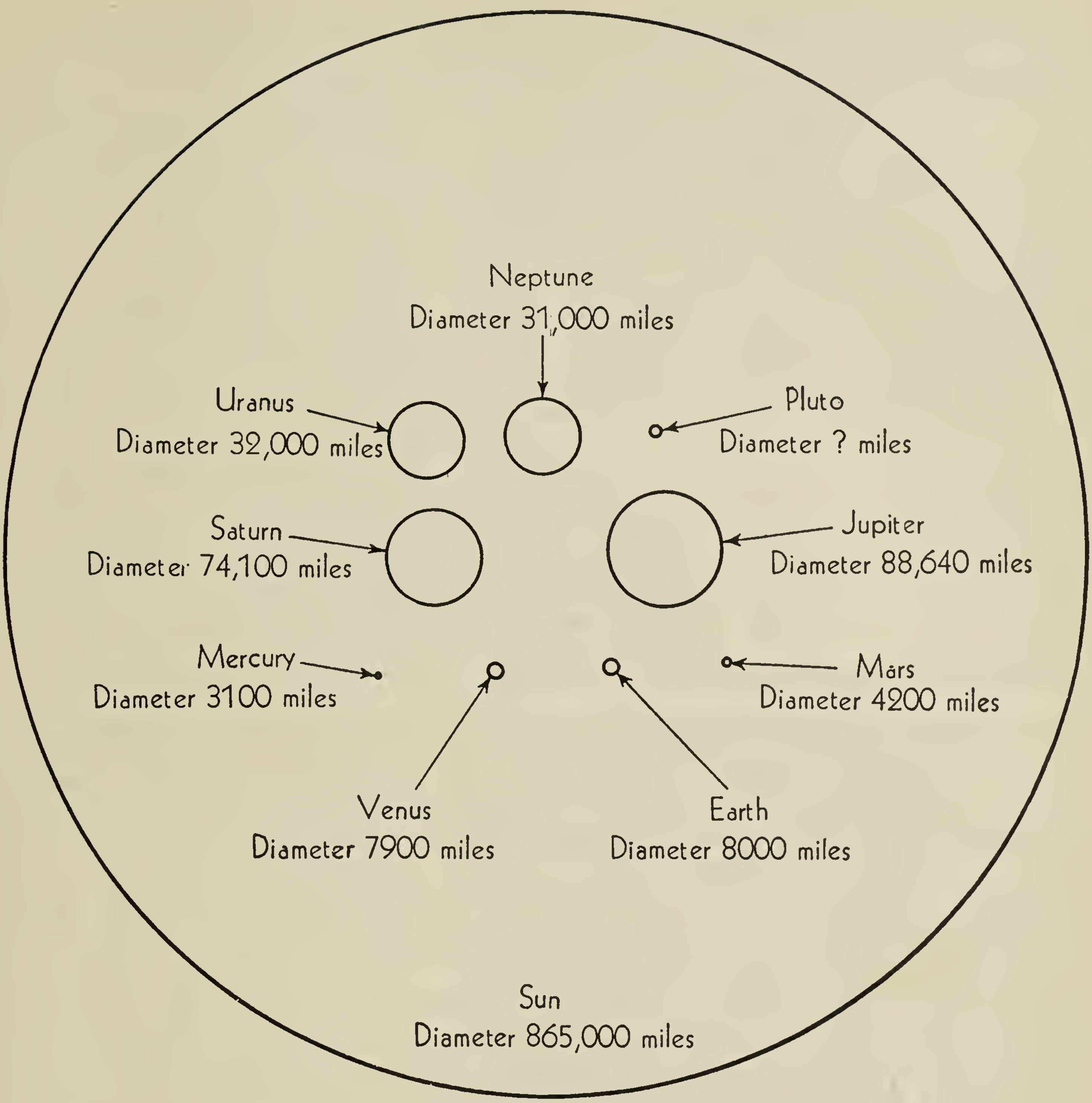
Astronomical Study Has Changed Man's Conception of the Solar System

Nine Planets of Different Sizes at Different Distances Revolve about the Sun. The early Babylonians were well acquainted with five of the planets. In reality they knew of six; but they never suspected that the sixth, the earth upon which they dwelt, was a planet also. The advent of the Copernican theory, together with the use of the telescope, resulted in a complete change in man's ideas regarding the sun and the planets. The earth itself was now added to the planetary group. Continued study and observation increased the number until now the total has been raised to nine planets. Whether there may be others, yet undiscovered, is not known. At present there is no evidence of their existence.

For years the planets had been recognized as falling into two groups of four each. The inner consisted of Mercury, Venus, Earth, and Mars; the outer, of Jupiter, Saturn, Uranus, and Neptune. Under this plan of grouping, the inner group is very different from the outer in many ways. The planets of the inner group are all much smaller and have a much greater density. The earth, the largest of the inner group, has a diameter of about 8000 miles, while Jupiter, the greatest of the outer group, is 88,000 miles through. The average density of the inner ones is 5 times that of water, while the outer ones are on the average but 1.5 times denser than water.

In addition to the planets proper, out between the orbits of Mars and Jupiter there is a "flock" of tiny planets, or planetoids, as they are often called. They vary in size from five hundred miles in diameter down to mere rocks a few miles through. These are sometimes spoken of as asteroids, and astronomers are uncertain as to whether they may be the remains of an exploded planet or fragments of matter from the pre-solar body which, for some unknown reason, did not unite to form another planet.

Aside from the scattered and relatively insignificant planetoids, it was seen that the planets rather naturally fell into two groups. Recently, however, the problem has been complicated by the discovery of Pluto, the ninth planet. Although it has not been fully studied yet, it does not appear to agree with the others of the outer group in many ways. Especially is this true with respect to size, since it is now estimated to be about half as large as the earth.


Neptune
Diameter 31,000 miles
Uranus
Diameter 32,000 miles
Pluto
Diameter ? miles
Saturn
Diameter 74,100 miles
Jupiter
Diameter 88,640 miles
Mercury
Diameter 3100 miles
Mars
Diameter 4200 miles
Venus
Diameter 7900 miles
Earth
Diameter 8000 miles
Sun
Diameter 865,000 miles

Relative sizes of the sun and the major planets

Drawn approximately to scale

Although there are nine planets proper, some of which appear very large in relation to the earth, their total mass is almost insignificant when compared with that of the sun. If the mass of all the planets taken together could be rolled into one ball equal in density to the solar body, its total volume would be but $\frac{1}{745}$ that of the sun.

At a distance of 36,000,000 miles Mercury is the closest of the planets to the sun. As we progress outward from the sun in our survey, the distance increases greatly until we come to Neptune, which revolves at a little more than 2,750,000,000 miles away. Now the recently discovered Pluto has a position which the astronomers estimate to be about 4,000,000,000 miles away from the sun, out in cold, dimly lighted space.

Table of Planetary Data. (Courtesy of Yerkes Observatory.)

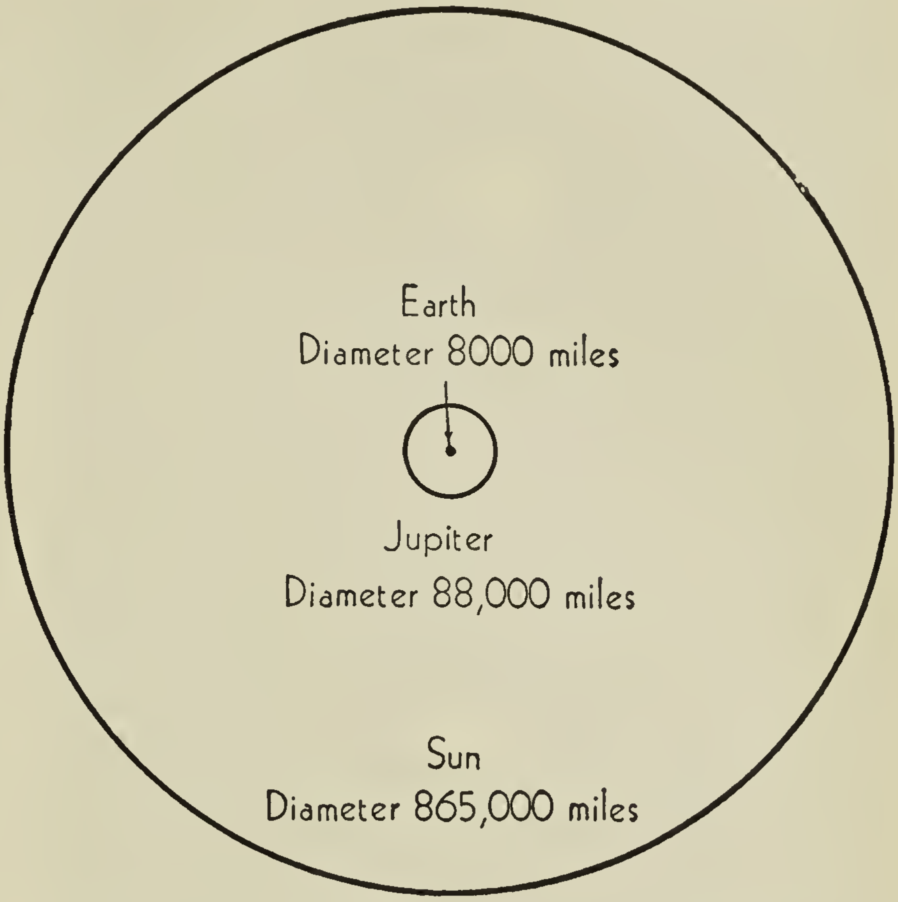
	Name	Symbol	Mean Distance from Sun		Period of Revolution		Eccentricity of Orbit	Inclination to Ecliptic
			Astron. Units	*Millions of Miles*	*Sidereal*	*Synodic*		
Inner					days	days		
	Mercury	☿	0.3871	35.95	87.969	115.88	0.206	7° 0′
	Venus	♀	0.7233	67.18	224.701	583.92	0.007	3 24
	Earth	⊕	1.0000	92.87	365.256	———	0.017	0 0
	Mars	♂	1.5237	141.50	686.980	779.94	0.093	1 51
					years			
	Ceres	①	2.7673	257.00	4.604	466.60	0.077	10 37
Outer	Jupiter	♃	5.2028	483.2	11.862	398.88	0.048	1 18
	Saturn	♄	9.5388	885.9	29.458	378.09	0.056	2 29
	Uranus	♅	19.1910	1782	84.015	369.66	0.047	0 46
	Neptune	♆	30.0707	2793	164.788	367.49	0.009	1 47
	Pluto		39.4574	3670	247.697	366.74	0.249	17 9

Name	Equatorial Diameter in Miles	Mass ⊕ = 1	Density Water = 1	Period of Rotation	Inclination of Equator to Orbit	Oblateness	Stellar Magnitude*
Sun ☉	864,100	331,950	1.41	$24^{d}.65$	7° 10′	0	− 26.7
Moon ☾	2,160	0.012	3.33	27 .32	6 41	0	− 12.6
Mercury	3,100	0.04	3.8	88		0	− 1.2
Venus	7,700	0.81	4.86	30?		0	− 4.3
Earth	7,927	1.00	5.52	$23^{h}\,56^{m}$	23 27	1/296	———
Mars	4,215	0.11	3.96	24 37	23 30	1/192	− 2.8
Jupiter	88,640	316.94	1.34	9 50	3 7	1/15	− 2.5
Saturn	74,100	94.9	0.71	10 14	26 45	1/9.5	− 0.4
Uranus	32,000	14.7	1.27	10 45	98	1/14	+ 5.7
Neptune	31,000	17.2	1.58	15 48	29	1/40	+ 7.6

*At mean opposition.

Though the planets all shine, none of them are believed to be self-luminous. Like precious stones, they shine with borrowed light. While some light from the distant stars reaches all of them, its total effect is negligible. Their luminosity is produced almost entirely by light whose source is the sun. It is difficult to imagine a great dark body like the earth, for instance, acting as a mirror; yet it does. Much of the sunlight that strikes the planet is absorbed and transformed into heat, to be sure, but enough of it is reflected to make a planet shine when it is observed from another planet. No better evidence of this fact can be found than the darkened effect produced on the moon when the sunlight is cut off by an eclipse.

The Discovery of Neptune Exemplifies the Scientific Method of Problem-Solving. When a planet is once located and its relation to other heavenly objects ascertained, its subsequent movements can be calculated with amazing accuracy. From that point on, its movement and position at any time become mere matters of mathematical computation.



Relative sizes of the earth, Jupiter, and the sun

Drawn approximately to scale

These relations were worked out for Uranus. For the first forty years after its discovery it followed the path of rectitude expected of all well-behaved planets. Then, for some unexplained reason, it began to deviate from its course. Ten years later it had departed even farther from its calculated place. By 1841 it had clearly exceeded the bounds of good planet behavior, and its irregular movement had carried it far from its appointed place. By this date the discrepancies, as Moulton says, "were intolerable to astronomers." As Moulton further says, this does not mean that it was found in an entirely different part of the sky from that in which it had been expected. Far from it. Indeed, the predicted and observed positions were so close together that, had a planet of the same size been at each of them, the two bodies would have looked like one "star" to the unaided eye. Yet a difference of this magnitude could not be tolerated by careful mathematical astronomers.

As astronomers puzzled over this difficulty, it was soon suggested that the erratic behavior of Uranus might be due to the gravitational pull of some other celestial body, possibly another as yet undiscovered planet. This suggestion appealed to astronomers. Consequently it was followed up and led to one of the most spectacular discoveries recorded in the pages of scientific history. We shall let Sir Richard Gregory relate it in his own words:

> After the planet Uranus had been discovered in 1781 by Sir William Herschel, astronomers calculated the path in which it moved, and predicted the positions it should occupy from time to time. The planet was found, however, to be slightly

behind or ahead of its calculated position. If we know a train is moving at a certain rate, we can say where it ought to be on the line at a certain time, and if it is not there we assume that something has happened. So it was with the planet Uranus: the difference between the actual and the calculated positions of the planet was assumed to be due to the disturbing influence of some unknown body beyond it.

There was every confidence that a massive globe somewhere in the darkness of space was making its presence manifest; and though the problem of finding the place of the disturber was very difficult, it was solved by two mathematicians—one an Englishman named Adams and the other a Frenchman named Le Verrier. In September, 1846, Sir John Herschel, son of Sir William Herschel, said: "We see it [the probable new planet] as Columbus saw America from the shores of Spain. Its movements have been felt trembling along the far-reaching line of our analysis with a certainty hardly inferior to that of ocular demonstration." On the twenty-third of the same month a German astronomer, Dr. Galle, found the new body close to the place which calculation had shown it ought to occupy. This is probably the greatest triumph of mathematics applied to the law of gravitation yet achieved.[1]

A result like this illustrates one of the finest services that science can render to man. It enables him to see that this is a universe of cause and effect in which the order of events may be successfully predicted. In the practical affairs of life also, certain results always follow certain causes, whether the problem is building a successful personal career or making an efficient airplane.

The Planets Have Satellites. As was once said, the solar system is not unlike a circus with its side shows. The main spectacle is furnished by the stately march of the planets around the sun. The side attractions are found in the procession of the moons about the planets.

For years the known planetary moons were twenty-six, but a few years ago Nicholson of the Mount Wilson Observatory found two new moons of Jupiter, which pushes the number of moons now recognized up to twenty-eight. Saturn has nine, Jupiter eleven, Uranus four, Mars two, and the earth and Neptune one each. Some of these moons are small, and some are large. Scarcely any of them are as large as the earth's satellite except the larger ones of the planets Jupiter and Saturn.

The Earth's Satellite. The earth's moon has the most human interest, not only because it is one of the most magnificent of all the planetary moons but also because of our having viewed it from childhood and grown familiar with it.

Careful calculations place the moon at an average distance of 240,000 miles from the earth. Its diameter is slightly more than 2000 miles, or one fourth that of the earth.

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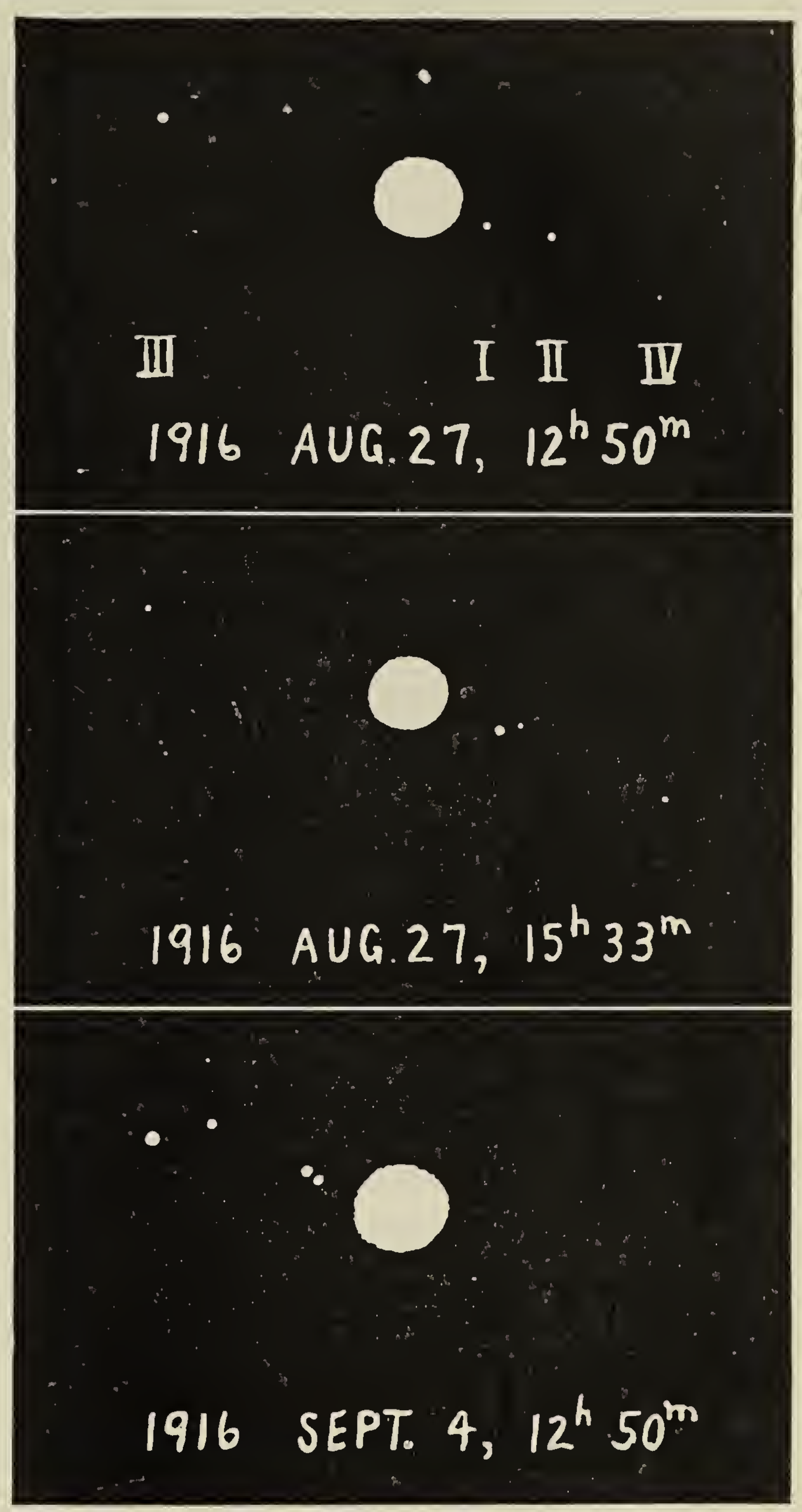
[1] Sir Richard Gregory, *Discovery, or The Spirit and Service of Science*, p. 175. By permission of The Macmillan Company, publishers.

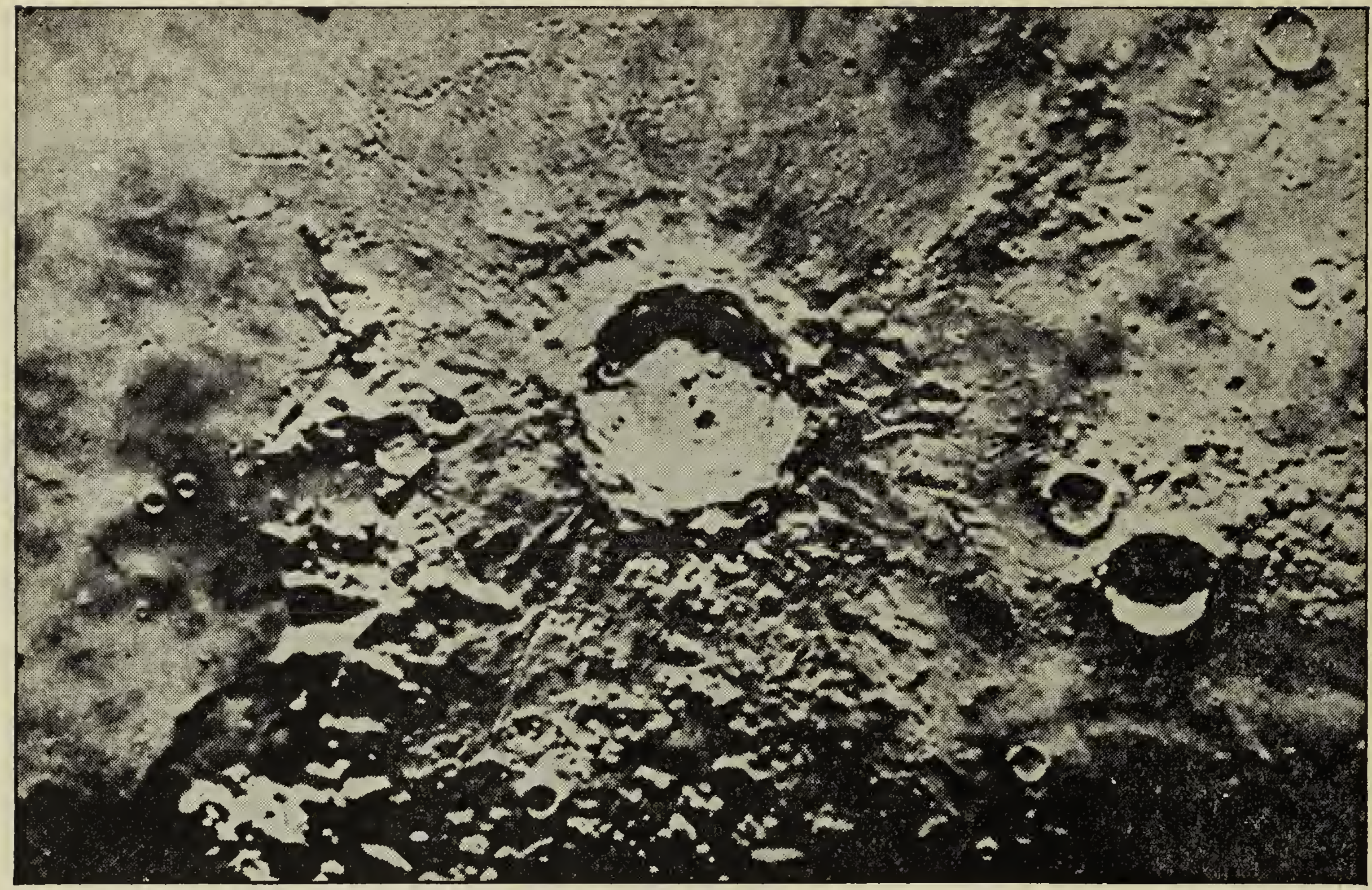
Being so close to the earth, every part of its visible surface has been studied minutely. The large telescopes, under the best atmospheric conditions for seeing, bring it to an apparent distance of but fifty miles. Under this magnification objects three hundred feet long could be made out on its surface. The moon is but 60 per cent as dense as the earth, and for that reason it has a mass but one-eightieth as great. Because of this characteristic its gravity is but one sixth that of the earth. In other words a good high jumper on the earth, if transported to the moon, could clear the bar at forty feet, and a pole vaulter could arch over a spire eighty feet high, if he had a suitable pole long enough.



Yerkes Observatory

Four of Jupiter's satellites

The surface of the moon is not a level, monotonous plain. It does have extensive plains, but it also has lofty mountain ranges. The Lunar Apennines are a range of mountains 400 or 500 miles long and rival the Andes of South America in height. Some portions of the Doerfel range include peaks that stretch up 26,000 feet in altitude. These mountains are higher than any on the earth with but very few exceptions. The mountains of the moon are most beautiful and picturesque. Since there is no atmosphere, there can be no rainfall or wind and consequently no erosion. For this reason the mountains are steep and their sides jagged. Near the summit the tall, angular peaks stretch up like unworn spires, just as they were formed by the great internal forces that caused their upheaval.



Yerkes Observatory

Crater Copernicus, one of the large craters on the moon

The plains on the moon's surface are dotted here and there with huge sharp-edged craters that stand out like great cosmic pockmarks. These gigantic depressions far exceed in rugged outline and configuration the largest volcanic craters on the earth. Some of them are 10,000 feet deep, and the crater Copernicus is 56 miles in diameter; the crater Tycho is 80 miles across. Altogether over 30,000 of these strange lunar depressions have been located and mapped.

Since the gravitational pull of the moon is so low, it is believed to have no atmosphere, as has been said. In the course of its development some gas was probably squeezed out of its interior. Once freed from the solid materials that generated them, the molecules of gas, by repeated collisions with one another, gradually worked farther and farther out from the surface of the moon. Finally, one by one they passed entirely outside the sphere of the moon's effective pull and went drifting off into the vast reaches of space. Some may have traveled indefinitely; indeed, they may be going yet. Others of these particles coming within the range of the gravitational pull of neighboring heavenly bodies may have been pulled down to form a part of their gaseous envelope.

The jagged condition of the lunar mountains and craters furnishes strong evidence that the moon has no atmosphere. Erosion would most certainly round off these prominences if atmosphere and water vapor existed. Moreover, the spectroscope shows no indication of an atmosphere.

Bryan from Pix

A bomb hole on a Warsaw street

Compare with crater Copernicus

The movements of the moon are also peculiar. Like some of the planets its periods of rotation and of revolution are equal. For this reason it always presents the same face to the earth night after night. Since the moon's rotation is accomplished in between twenty-seven and twenty-eight of our days, the lunar days and nights are each approximately fourteen days long.

The strangest of temperature relations must exist on the moon. With no atmosphere to refract and dissipate the light beams, there must be neither dawn not twilight there. Full daylight and sunshine must burst forth almost instantaneously, and the intense sun's rays must shine with unabated vigor during the whole long day. With no clouds or air to conduct the resulting heat away by convection currents the temperature of the surface must be very high. Earth temperatures over the very center of the Sahara in the dead of summer must be cool and invigorating by comparison. It is quite probable that the intense heat would boil water, even at the pressure of our atmosphere, if it existed there, and make the rocks crack with expansion.

On the other hand, within a few hours after the sun sinks below the horizon, the very opposite conditions must begin. With no clouds or water vapor to blanket the moon, the heat would soon radiate away. The mercury in the thermometer (if there were one) would drop rapidly to the freezing point of mercury. Then, for fourteen long days and nights, temperatures far more frigid than those of winter in the remote polar regions would prevail. These would continue until the lazily turning moon again brought this side facing the sun.

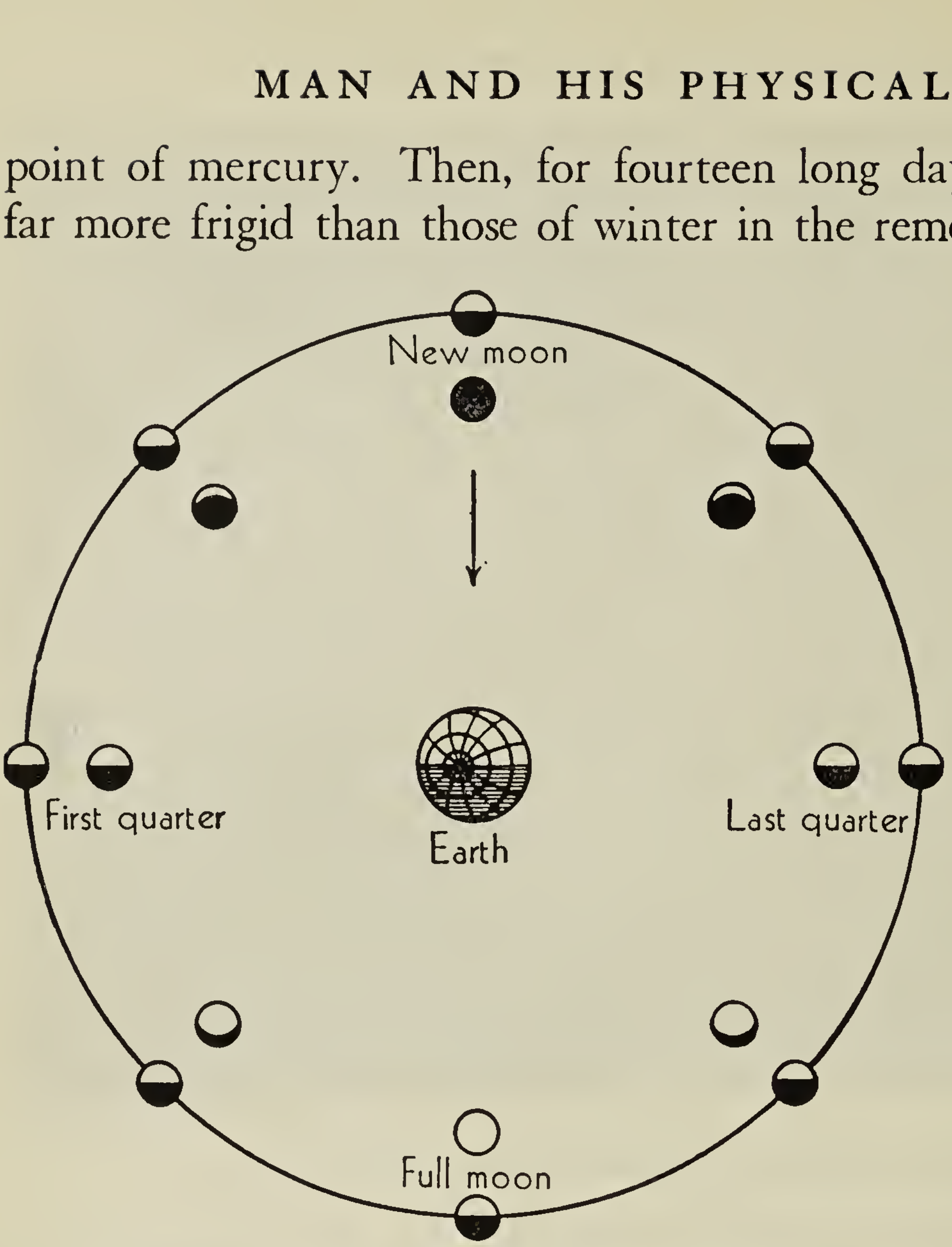


Diagram to illustrate the phases of the moon

The arrow indicates the direction of the sunlight. The inner row represents the phases of the moon as seen by an observer on the earth

One of the most interesting features of the moon in relation to the earth is its phases. Thus we have the gradual succession of changes from new moon to full moon and from full moon to new moon. These effects are each produced by the different positions which the moon takes with reference to the earth and the sun during its revolution. At new moon it is on approximately the same side of the earth as the sun, and at full moon it is on the side of the earth opposite the sun. At the quarters it is halfway between these points, with the positions of first and third quarters lying opposite each other on its orbit. The increasing change from new moon to full moon and the decreasing light following full moon again are all produced by the enlarging or diminishing portion of the moon's sun-lighted face which we on the earth can see.

The moon, despite its gladsome appearance and its silvery glow, is a cheerless place to contemplate. The alternate periods of intense cold and heat must have succeeded each other in monotonous rounds throughout the whole period of lunar history. Moreover, they doubtless will continue for millions of years to come. With no air a deathlike stillness would prevail; not the song of a single bird, a rush of wind, or the sound of a human voice could relieve the oppressive silence. A flash of light might be seen occasionally as infalling meteorites struck the surface, but no report could follow to make even that event complete. Such considerations lead us to appreciate the earth more and make us content to view the moon from a distance.

The Spatial Relationship Maintained by the Celestial Bodies May Be Explained on the Basis of Newton's Laws of Motion and Gravitation. One of the interesting aspects of the heavenly bodies is the tendency which they have to maintain their spatial relationships. We have found that multiple stars circle about their common center of mass, and that within the galaxy all stars weave in and out among one another like "bees in a swarm." When we come to the planets and satellites, one of their most fascinating features is the stately march which each makes around its central body.

At the outset there was apparently no understanding of the forces that "make the heavens go." Even Kepler, who died in 1630 and was perhaps the greatest astronomer of his day, knew practically nothing of these forces. In fact, "Kepler seems to have been somewhat inclined to attribute" the force that makes a planet move "to the will of a supernatural being." He thought that it might have been an angel that had charge of the planet or some invisible spoke that radiated out of the sun to the planet and pushed it along.

It remained for Newton, the renowned English mathematician, who was born in 1642, to open up the great field of celestial mechanics and start the world thinking correctly concerning these problems. His initial work in this field was based on what are known as Newton's laws of motion. They may be stated as follows:

1. *A body at rest remains at rest, and a body in motion moves at a uniform velocity in a straight line, unless compelled to change that state by some external force.* This law is most frequently known as the law of inertia. It is often stated thus: A body tends to continue in its present state, whether of rest or of motion. For instance, a large rock would lie on a hillside for centuries without moving, unless it were disturbed by some force from without. On the other hand, Newton reasoned that a celestial body moving in space would be practically free from friction; therefore, when given an initial impulse, it would continue to move for millions of years, or indefinitely, at the same velocity in a straight line, unless acted upon by some outside force.

2. *The force required to accelerate a body is proportional both to its mass and to its acceleration, and the direction of the acceleration will be the same as that of the force.* Whenever the velocity of a body changes, we say the body is accelerated. Thus, if an automobile at rest is made to attain a velocity of five miles per hour, it has been accelerated. Newton's second law states that a force is required to give the automobile this acceleration, and, if friction is disregarded, no force would be required to keep it at this velocity; that is, with no force there would be no acceleration. Furthermore, this law states that the magnitude of the force required would be directly proportional to the

acceleration and to the mass of the automobile. For example, twice as great a force would be required to accelerate the car to ten miles per hour in the same amount of time; or twice as great a force would be required to accelerate a car twice as heavy to five miles per hour, in the same time. In all cases the acceleration must be in the direction of the acting force.

3. *To every action there is an equal and opposite reaction.* Suppose that two boats freely floating on quiet water are connected by a rope. Suppose further that one boat weighs 10,000 pounds, whereas the other weighs but 1000 pounds. Moreover, assume that the rope is pulled on by two winches, one on each boat. Then, according to the third law, the force on the winches must be identical. According to the second law, both boats will be accelerated toward each other, but the smaller one will be accelerated faster. In fact, if frictional forces are disregarded, the smaller boat should be accelerated ten times as fast as the larger one.

Newton's Laws of Motion Had to Be Supplemented by an Active Force. Newton's laws of motion were not enough to explain all the spatial relations between bodies observed either in the heavens or on the earth. They accounted for much of the behavior of a body at rest or in motion, but not all of it. For instance, why does the moon continue to circle the earth, or the planets the sun, instead of going off in straight tangential lines? Or why does a ball suspended above the earth by a wire drop to the ground instantly if the wire is cut? According to the law of inertia one would expect the moon to move in a straight line and the ball to remain poised in mid-air unless some external force acted on these bodies.

Tradition has it that Newton got his first inspiration toward the solution of this problem from a rather trivial incident. One day, as he lay at leisure in an orchard, he saw an apple fall from a tree. He was such an ardent student of forces and of motions that straightway he began to ponder on the question of what made the apple fall. His laws of motion would account for its falling after it got started. But the question was What made the apple begin to fall after being detached from the twig?

While Newton was a student at the University of Cambridge in 1665, the Great Plague was sweeping the city. The situation became so bad that the institution was closed, and he was compelled to return to his home. But his inquiring mind, still disturbed by the memory of the apple incident, could not, like the minds of most of his fellow students, sink back into idle leisure. So in the quiet of the country he began that long series of reflections and calculations which resulted in his laws of gravitation. It occurred to him that the force which caused the apple to fall might be the same one that was pulling the planets out of a straight course into a circular path about the sun. It also occurred to him, that the same force might explain the revolution of the moon around the earth or the courses of comets about the sun.

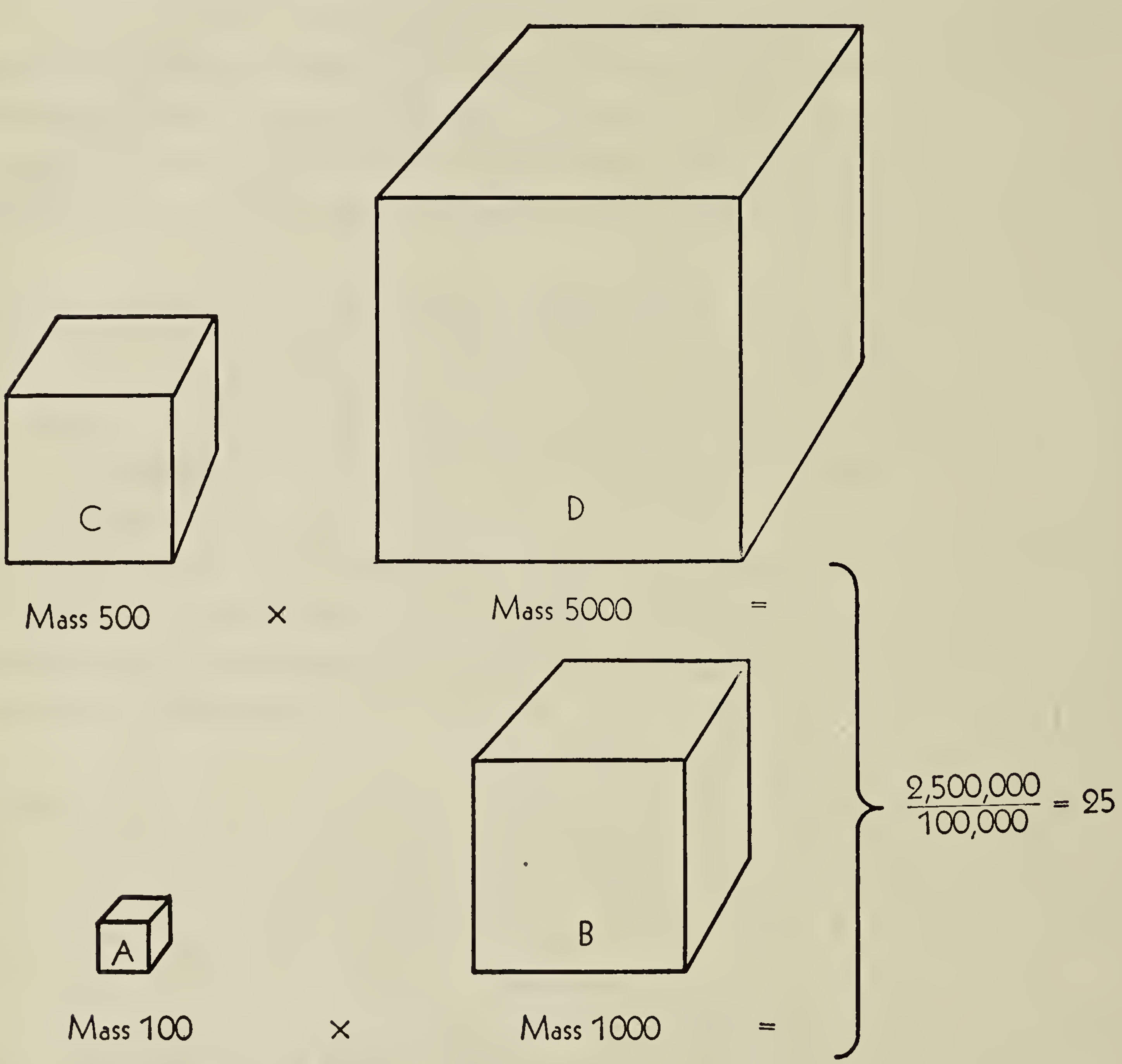
At length Newton struck upon the idea that all bodies in the universe have some kind of attraction for one another. This conception he formulated into a law known as the *law of universal gravitation*. Newton expressed it as a single law, but for the sake of simplicity we will break it up into three parts, which may be stated as follows:

1. *Every particle of matter in the universe attracts every other particle of matter.* Gravitation is supposed to be the primordial form of force, one that is inherent and perpetual in every atom of matter in the universe. When one throws a ball straight up into the air, its progress upward is retarded by the attraction of the earth. Presently it stops and starts to descend. As the ball falls, its movement is constantly accelerated, and in a moment it strikes the ground again with a thud. Although its action is so common as scarcely to challenge our attention, we have observed a really very strange physical phenomenon. What is this force that, acting without the intervention of lever, pulley, belt, or cable, pulls bodies together in the universe? Several theories have been advanced, but no one can adequately explain it.

The force of gravitation is a very feeble one. In fact, as exerted between two bodies on the earth, it entirely escapes the notice of the average man. Only scientists have to reckon with it. But when the bodies reach the proportions of stars and planets, gravitation becomes an entirely different matter. Indeed, without it everyday life as we experience it would be quite impossible: the earth could hold no atmosphere; friction, so important in man's activities, would for the most part fail; bodies would have no weight; and most of our movements could not be carried out. Moreover, the spatial relations of all celestial bodies, as we shall see presently, would soon be radically changed.

2. *The gravitational attraction between two bodies varies directly as the product of their masses.* Thus on page 100, if the mass of body A be taken as 100 and that of body B as 1000, then 100×1000, or 100,000, equals an expression for their attraction. Now between bodies C and D, each of which is respectively five times as massive as A and B, the numerical expression of their attraction would be 2,500,000. Then the attraction between C and D, as compared with that between A and B, would be $\frac{2,500,000}{100,000}$, or 25.

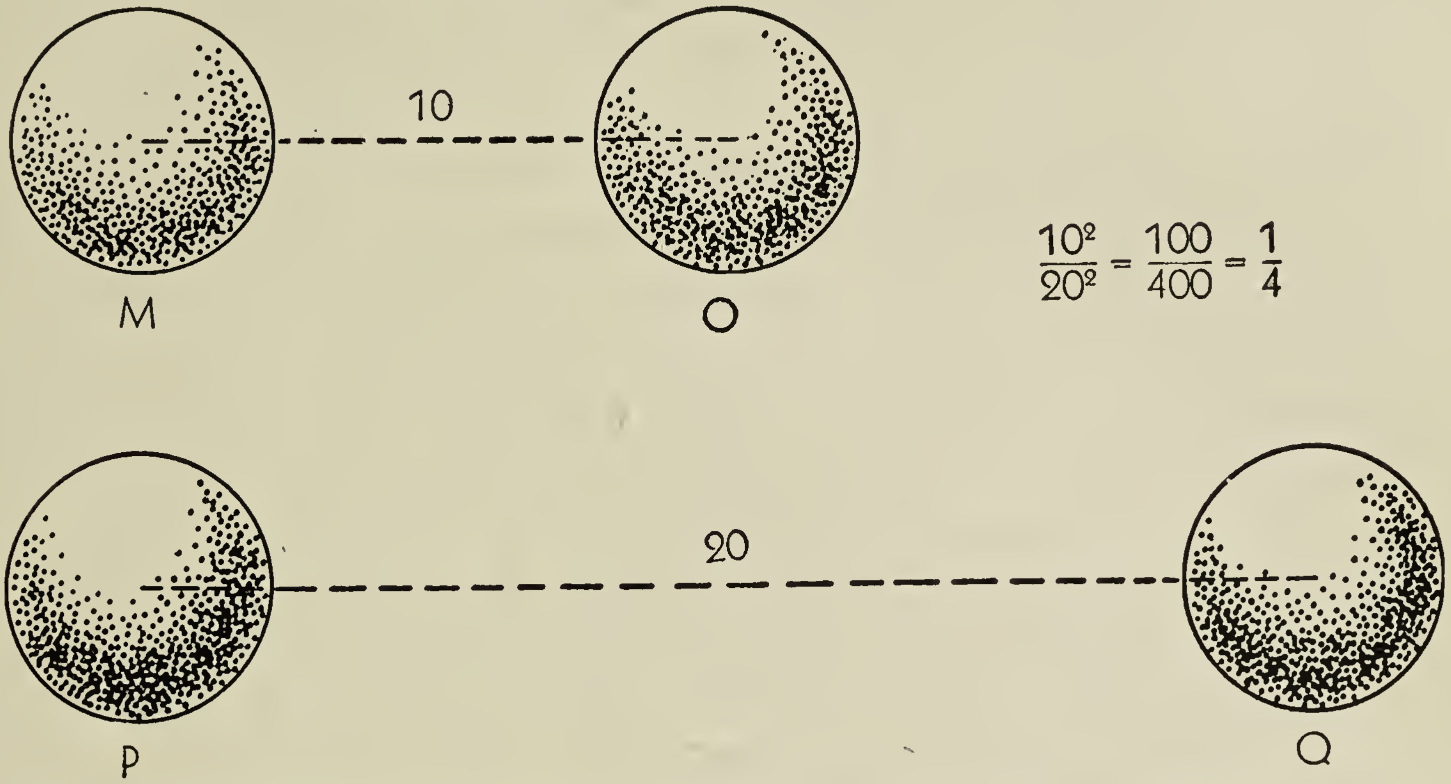
To see the application of this law in everyday life, let us return to Newton's experience with the falling apple. If between every two particles of matter there is a mutual attraction, then not only did the earth pull the apple, but the apple also pulled the earth. The only reason why the apple fell downward to meet the earth, instead of the earth's visibly falling upward to meet the apple, was that the earth, being so much more massive, possessed greater inertia. Had the earth and the apple been equally massive, they both would have moved and thus would have met halfway between their original positions.



Gravitational attraction between two bodies varies directly as the product of their masses

3. *The mutual attraction between two bodies varies inversely as the square of the distance between their centers of gravitation.* To illustrate, take the two spheres *M* and *O* in the diagram on page 101. Let the distance between their centers be 10 and let *P* and *Q* represent the same bodies moved out to twice the distance, or 20. Now Newton postulated, as a result of his studies, that this mutual attraction must grow less as the bodies move farther apart and that this force must diminish at a rate equal to the square of the distance between them. In other words, the square of the distance between *M* and *O* is 100;

between *P* and *Q* is 400. Then the attraction between *P* and *Q* is related to that between *M* and *O* as $\frac{100}{400}$, or $\frac{1}{4}$.



Gravitational attraction between two bodies varies inversely as the square of the distance between their centers of gravitation

As further illustration, consider the following: A man's weight is the mutual attraction between his body and the earth at a point approximately 4000 miles from the earth's center of gravity. Now imagine a man weighing 160 pounds at the earth's surface to be carried to a point 4000 miles above the earth's surface, or 8000 miles from the earth's gravitational center. His weight, which would now be much less, could be calculated from the following inverse proportional equation:

$$160 : x : : 8000^2 : 4000^2$$

When this equation is solved for x, the man's weight is found to have shrunk to 40 pounds. Owing to this rapid fall in the pull of gravity, were the man carried to the distance of the moon, and there were no moon there to attract his body, his weight would be just about seven tenths of an ounce.

The Movement of the Celestial Bodies Is Governed by the Laws of Motion and Gravitation. With Newton's laws of motion and his laws of gravitation now in mind, we are ready to consider the movements of the heavenly bodies. Scientists cannot always explain what gave nebular clouds, stars, and island universes the initial impulses to start them on their way. In many instances great cosmic forces in addition to gravitation must have been involved. Concerning the origin of the movement of the planets and their satellites, the astronomers have a hypothesis, as will be noted later. But, once these celestial bodies were set in motion, they would continue in a certain path to the end of time unless they happened to pass within the spheres of attraction of other heavenly bodies or unless their masses were changed. Since there is no air out in endless space, there would be no friction to slow them down.

All bodies in the universe attract all other bodies with a force depending both on their masses and on the distances between them. As long as they are very far away from one another, this force is too feeble to be evident. But let them come close enough together as they pass by one another in space, or let them be formed in relatively close proximity, as the sun and the planets are believed to have been, then gravity becomes a very conspicuous and active force. This may be seen in the case of the planets circling the sun and in the case of each satellite moving around its central body. Instead of moving on into space in a straight line, they move in curved orbital paths about the central attracting bodies. There is an exact balance between the gravitational attraction tending to pull the moon toward the earth, and the other planets toward the sun, on the one hand, and the forces tending to keep them moving in a straight line, on the other. By a similar balance of gravitational forces the whole solar system is kept intact.

If several bodies—different stars, let us say—come close enough to a single other body, such as another star, to exert appreciable mutual attractive forces on that star, then the course of that star through space will be determined by the resultant of all the stellar attractive pulls acting on it.

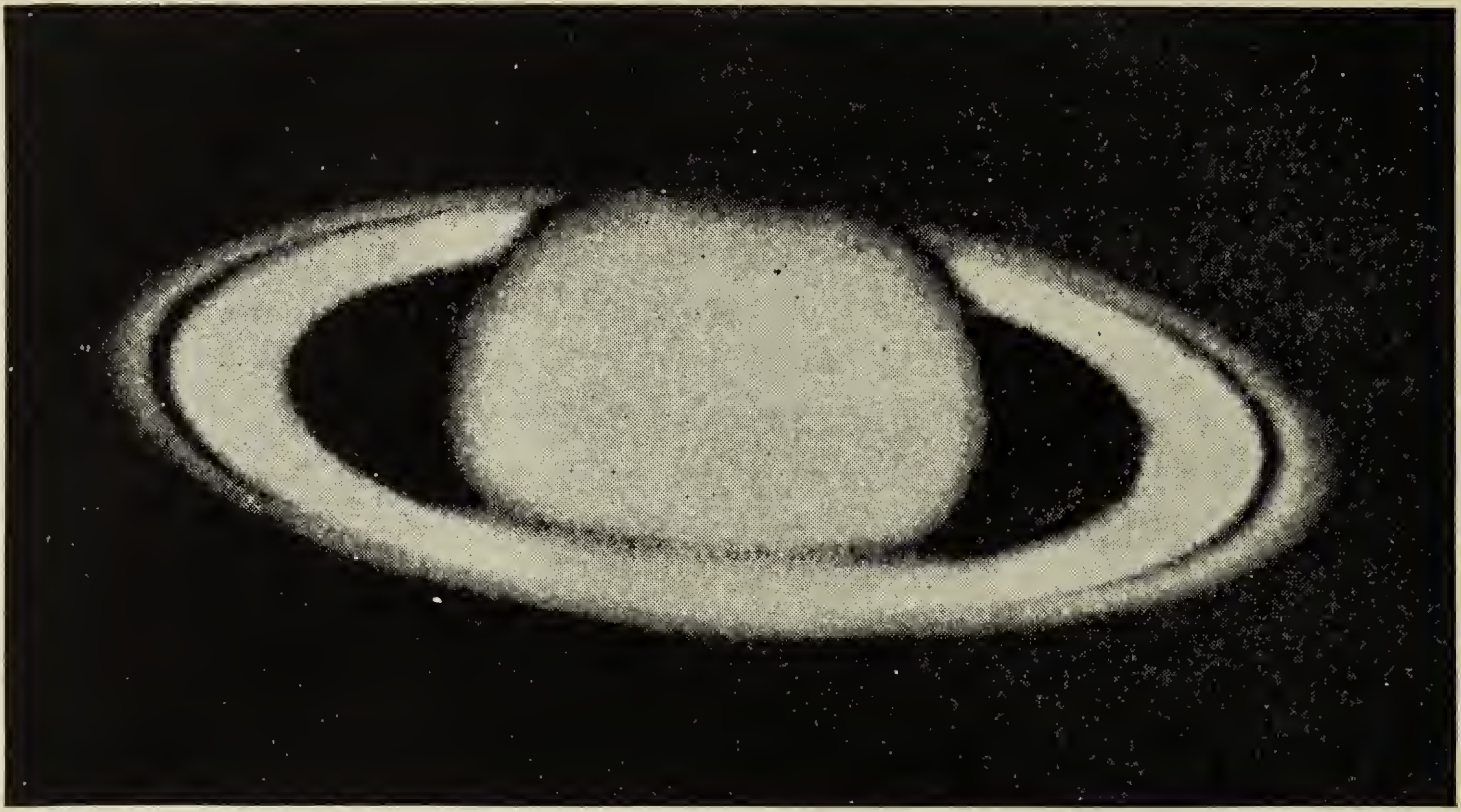
Now every star in our galaxy, as it moves along, must be acted on by the gravitational pull of many other stars. Some of these attractions must be relatively weak and others relatively strong, depending on the masses and distances of the stellar neighbors. Consequently any star under consideration would deviate in its course, now in this direction and then in that direction, in response to the constantly changing forces pulling on it. In this way inertia and gravitation would readily account for the movement of the stars within our galaxy "like bees in a swarm."

When applied to the solar system, it is astonishing to the uninitiated how invariable these laws of cosmic motion are. Mathematical astronomers, by applying them, can compute the time of an eclipse of the moon or of the sun fifty years hence down to the very second when it will occur. Indeed, they can determine just what portion of the earth it will cover and how long it will last. Or if a comet that has appeared before is to be considered, they can tell us just when it will come in sight once more and in what part of the sky it will appear, even if its gigantic swing has carried it so far out into the heavens that it will not come into view again for seventy-five years, as in the case of Halley's comet. When a new comet appears, astronomers can calculate whether it will come back again and how soon, or whether its orbit is such that it will never return.

Different Hypotheses Have Been Advanced to Explain the Formation of the Solar System. Since the verification of the Copernican theory, men have wondered how the solar system was formed. The scientist feels that everything which exists in the world of nature can be explained on the basis of cause and effect. Certain forces and cosmic materials, he feels, must have worked together to form the solar system. But what were the original materials and the primeval forces, and how did they interact? These are the questions that puzzle him. Two leading hypotheses have been proposed.

The Laplacian Hypothesis. The earlier of these is known as the Laplacian hypothesis, named in honor of Simon Laplace, a Frenchman, who formulated it in 1796. According to his theory a colossal nebula with a diameter at least as great as that of the orbit of the outer planet drifted about in space. For some reason it began to rotate, taking on a globular form. Particles falling toward the center speeded up its motion, and it became flattened at the poles and widened at the equator. Finally it assumed a huge, spinning, lens-shaped form. In time its rotational velocity became so great that an outer ring was thrown off. Perhaps it would be more accurate to say that the central part shrank away, leaving an outer ring. Subsequently the nebular material forming this outer ring settled together in some way to form the outer planet, which under the spell of the forces we have explained continued to follow the course of its orbit in the same direction in which its parent mass was rotating. In this way, as the spinning of the central body speeded up, ring after ring was successively thrown off, each of which later condensed into a planet. In time the central mass became so reduced that its speed was insufficient to cause a ring to slough off. This, then, as it condensed, became the central controlling body, the sun. The planetary moons were believed to have been formed from the original mass of each ring, much as the planets themselves had been formed.

This is indeed a simple explanation. Its steps seem plain and logical. If a questioning soul ventured to raise an objection, Laplace bade him look through the telescope at the planet Saturn surrounded by its rings. There he would find the model right before his eyes. As may be seen in the illustration on page 104, this planet is accompanied by a strange girdle of ornate rings. These rings are believed to be made up of tiny particles, and the diameter of the outer ring is about 171,000 miles. The width of the rings is



Yerkes Observatory

Saturn, with its complement of rings, was used to verify the nebular hypothesis

approximately 37,500 miles. Saturn, according to the Laplacian hypothesis, was delayed in its formative processes and was still in the very act of making moons out of abandoned rings of matter.

But astronomical knowledge expanded, and as it grew, certain disconcerting facts came to light. The skeptics began to say that when a disk turns so rapidly that material is thrown off its outer rim, it does not part as a ring but, like drops of water from a grindstone, is hurled off particle by particle. Anyhow, continued they, if a ring should be thrown off, how could it all condense about a single nuclear center into a planet? What sort of combination of forces could exist to bring this about? Moreover, added the critics, there is Phobos, the little inner satellite of Mars, which spins around the planet almost three times as fast as the planet itself turns on its axis. If there is any difference between the two, according to the Laplacian hypothesis, Mars should rotate faster than Phobos revolves about it.

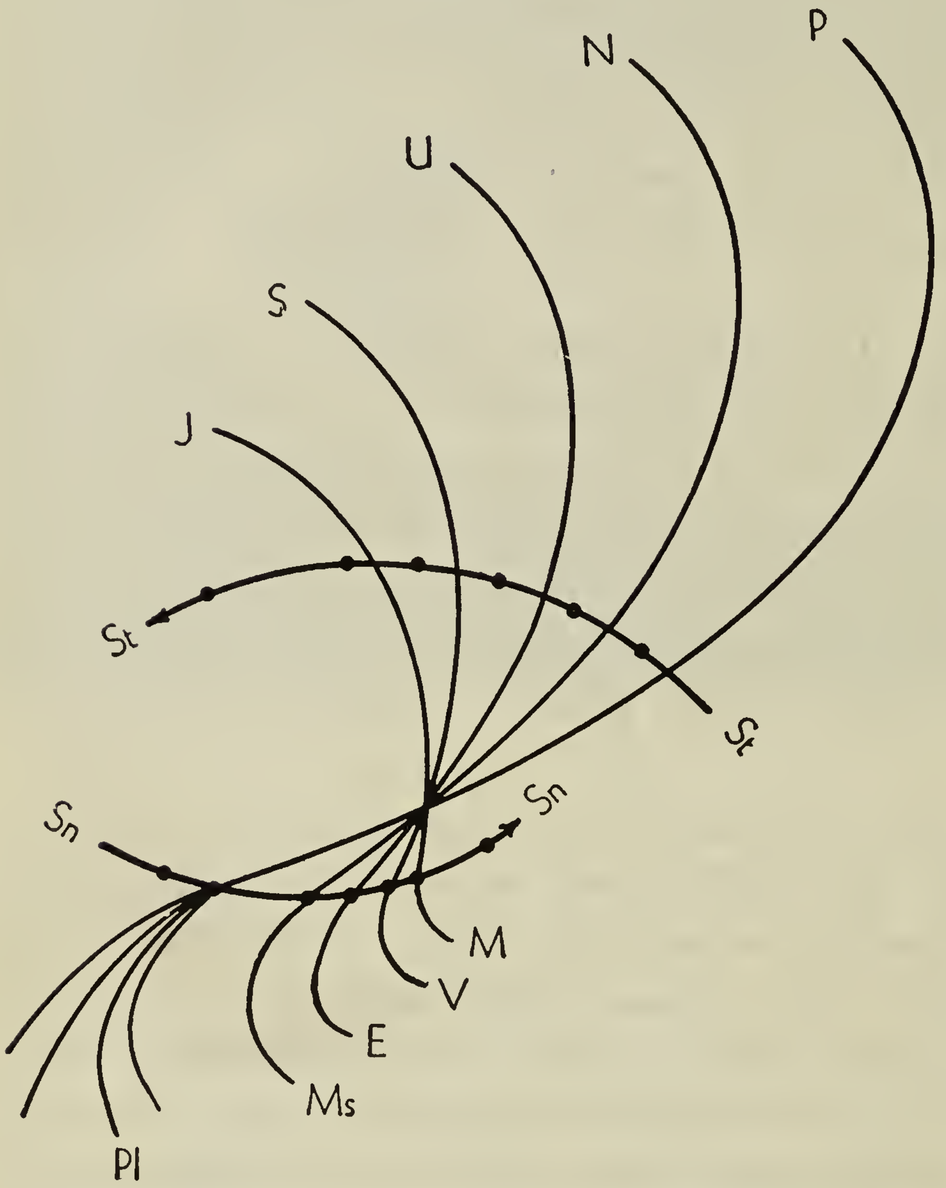
Finally, to note but one more of the less technical objections, what explanation can be offered for the eighth, ninth, and eleventh moons of Jupiter and the outer moon of Saturn, whose course in their orbits is backward as compared with the direction in which these planets themselves rotate? Certainly, if these satellites had been thrown off as rings, this change in direction could not have been acquired; for, according to Newton's first law of motion, they would have continued in the direction in which they were moving when they were yet a part of the central body.

Against these objections the hypothesis could not stand. It first began to totter and then finally fell from the sheer weight of the evidence piled up against it. Mere feeling alone almost makes us regret its downfall. The theory was such a beautiful one; besides it furnished such an easy explanation for those mysterious rings of Saturn. But every theory ultimately must either stand or fall on the basis of the facts that can be mustered to support or refute it. In this case the weight of evidence against the theory was too great. The Laplacian hypothesis had to go.

The Planetesimal Hypothesis. The ring hypothesis of planet formation was superseded by what may be termed the planetesimal hypothesis. According to this hypothesis, our solar system was formed from some presolar mass, consisting of perhaps a single star or possibly twin stars. Through the influence of gravitation, according to the hypothesis, a visiting star approached so close to this presolar mass as to set up cataclysmic disruptive tides. Indeed, one view holds that the celestial visitor actually grazed or collided with the presolar mass.

The planetesimal hypothesis was advanced by Chamberlin and Moulton of the University of Chicago. We shall attempt to present only the major points of the hypothesis. According to their idea all the material comprising the whole solar system originally made up a single star body. This star might have been an old, decrepit stellar body or even a cold, dark one drifting through space. As happens on an average once in a quadrillion years, some celestial body "called on" our solar-system-to-be. There was no collision, but these two stellar bodies passed in their cosmic course and paid each other their respects. Indeed, the visitor came so close as to set up a tremendous tidal force on the presolar body. Owing to this gravitational strain the stress finally became so great as to cause huge bolts of material to shoot out toward the passing star. Owing to polar compression mostly, corresponding bolts were extruded on the opposite side. Thus four large bolts of planetary stuff corresponding to the planets Neptune, Uranus, Saturn, and Jupiter were successively pulled out on the side next to the heavenly visitor. At corresponding times four bolts were extruded on the opposite side of the presolar mass, they being the planetary material that subsequently condensed into the planets Mars, Earth, Venus, and Mercury respectively.

Since Dr. Chamberlin's death Pluto has been discovered, which tends to support his idea that bolts of materials were simultaneously shot both forward and backward from the disrupting body. For heretofore the planetoids had stood out as an unbalanced enigma to the adherents of the planetesimal idea. Dr. Chamberlin's diagram shows them to have had no extruded counterpart out beyond Neptune. The discovery of Pluto, however, filled in this gap and makes the five outer planetary masses balanced by the five inner extrusions.



The origin of the solar system according to the planetesimal hypothesis

Sn, path of the presolar body; *St*, path of visiting star; *M–J*, tidal wave forming Mercury and Jupiter; *V–S*, Venus and Saturn; *E–U*, Earth and Uranus; *Ms–N*, Mars and Neptune; *Pl–P*, the planetoids and Pluto

Under the enormous pressure and the frictional and disruptive forces existing, these bolts of material were emitted mostly as gaseous matter, perhaps millions of miles through. They, of course, could not be sharp and clean in outline. More probably some of the gaseous matter and resulting particles strung along through the distance intervening between the bolts, much as some smoke intervenes between the larger puffs of a railway locomotive. Thus would be formed two more or less continuous arms of mostly gaseous matter extending from opposite sides of the residual mass. The main bodies of the bolts would be represented by nine nuclear masses scattered along in the arms.

Now our celestial visitor, whose call had been so eventful, passed on into outer space, but not until the pull of its gravitational force and the passage of the solar body had tugged at the disrupted mass in such a way as to set the whole system turning. Eventually it took on the aspect of a spiral with two opposing arms.

The visiting star could not have been a very massive one such as the giants Arcturus and Canopus; otherwise its gravitational force would have been so great as to strip off the whole arm of the spiral next to it and to pull the material of the dismembered arm into its own body. On the contrary, its size was just sufficient to force the arms out and set them whirling. As

Chamberlin says: "Our planetary family had an aristocratic birth. It was no everyday affair, even if it did not make much stir in the universe."

Once extruded, the material of the hot gaseous arms began to cool. Probably it resolved itself into liquid drops, which later cooled down to form solid particles, or planetesimals, from which the hypothesis is named. Gradually the planetesimals comprising the denser, nuclear regions would begin to condense by mutual attraction. At first the central bodies so formed were relatively small and pulled with a feeble force. They could draw in only those particles which happened to be near them. But as these particles came in, the gravitation of the central mass increased. Consequently its effective pull extended out farther, which in turn pulled in still other planetesimals. In this way it continued until all or practically all the internuclear material in the arms had been drawn in to enlarge the nuclei, which thereby became planets.

Eruption of Colima

Note the primary and secondary bolts [1]

The moons are formed from accretion about secondary centers found within or near the main gigantic puffs of expelled matter. The revolving motion of the moons is supposed to have resulted from the pull of the planet and the impulse given by the inrushing planetesimals. In this way revolution, either backward or forward, might be developed according to the manner in which the planetesimals came in. Thus the countermoving moons of Jupiter and Saturn could be explained.

The English astronomers have suggested a modified form of the planetesimal hypothesis, but it is so similar to Chamberlin and Moulton's ideas that we need not stop to consider it here.

Whether the planetesimal hypothesis can stand the test of time and further development of astronomical science, remains to be seen. If it is wrong fundamentally, it doubtless will be superseded by a wholly new conception as man's knowledge grows. If in the larger aspects it is sound, but erroneous in minor details only, then time will most surely correct these defects. Science must constantly revise and correct its hypotheses in the light of new knowledge. It will be interesting to see how time and the astronomers will deal with the planetesimal hypothesis.

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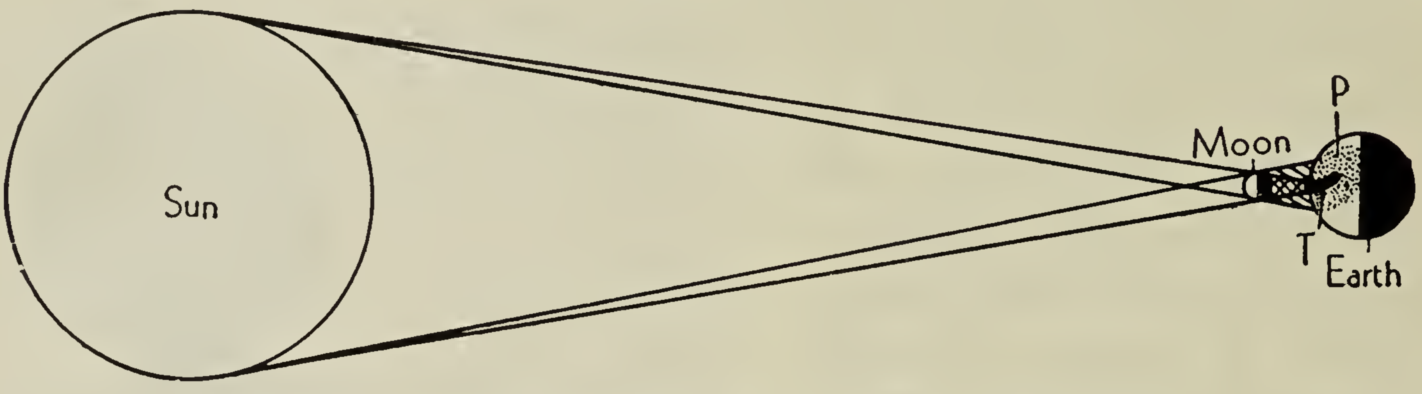
[1] From *The Two Solar Families*, by T. C. Chamberlin. By permission of The University of Chicago Press.



A diagram to show how the sun is eclipsed by the moon

Eclipses Are Caused by the Shadow of One Body Falling upon Another. Although the heavenly bodies are relatively thinly scattered through space, they sometimes get into such a position that the light of one is obscured from observers on the earth. When this happens, an eclipse is produced. Astronomers find eclipses of the multiple stars[1] to be much more numerous than those of the sun and the moon. But whether eclipses are solar, lunar, or stellar in nature, they are produced in the same way, that is, by the shutting off, from the earth, of the light of one cosmic body by another.

An eclipse of the sun occurs when the moon comes between the earth and the sun. Since the moon revolves around the earth and in an orbit whose plane is slightly inclined to the plane of the earth's orbit, periodically it comes into such a position as to cut off the rays of the sun from a part of the earth. The result is a moon shadow cast upon the earth—a solar eclipse. Because the sun is so much larger than the moon, the shadow is cone-shaped.

The apex of this cone-shaped shadow falls upon a small section of the earth's surface only, and in that area produces a total eclipse of the sun. To people within this small circle the whole face of the sun is obscured, and only the sun's corona, peeping up around the moon's rim, is observable. In addition to the deeply shaded area and surrounding it, there is a region from which all but a part of the sun's face is obscured. This area experiences a partial eclipse.

The total eclipse can last no longer than it requires for the point of the cone-shaped shadow of the moon to pass over a given point on the earth.

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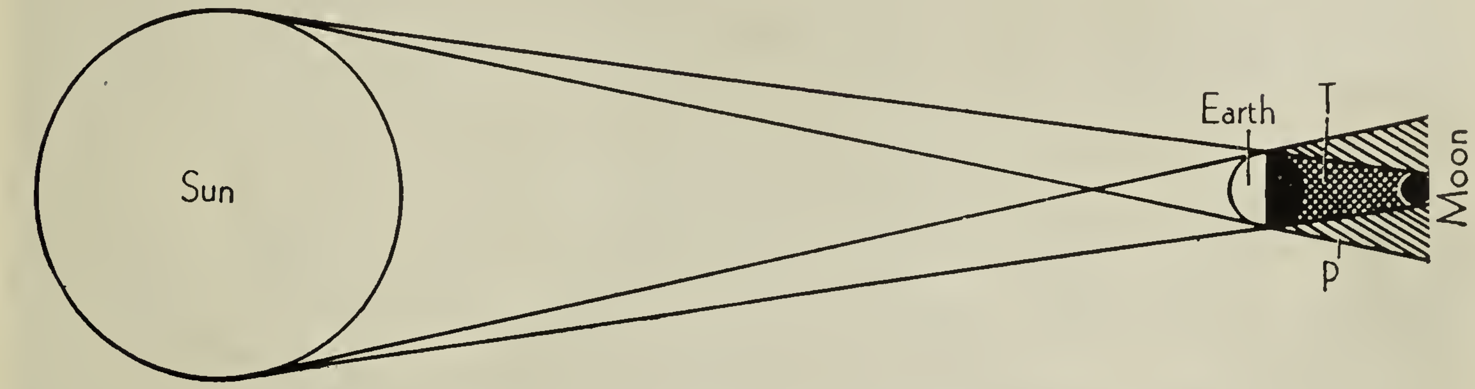
[1] Eclipses by direct interposition of one celestial object so as to hide another and not cast a shadow are called *occultations* by astronomers.

Its maximum duration is 7 minutes, 40 seconds. Sometimes, indeed, owing to the position of the moon, it is much shorter than this. In our latitude it is usually about 100 seconds in duration. Yet enthusiastic astronomers prepare for months before a solar eclipse is to take place. They provide themselves with telescopes, special photographic equipment, helpers, and everything needed for effective observation and records; they then travel, in some instances halfway around the earth, to reach the path of the eclipse. All this preparation is made for the purpose of, at the most, six or seven minutes' intensive study of the sun's corona and what it tells of solar conditions. Then, perhaps, it may be cloudy during those precious minutes. Results: disappointment, failure, and a long trek back home. Such eventualities, nevertheless, must be bravely faced by every devoted scientist; for, along with many fruitless attempts, some successes are wrested from nature, and thus scientific knowledge grows.



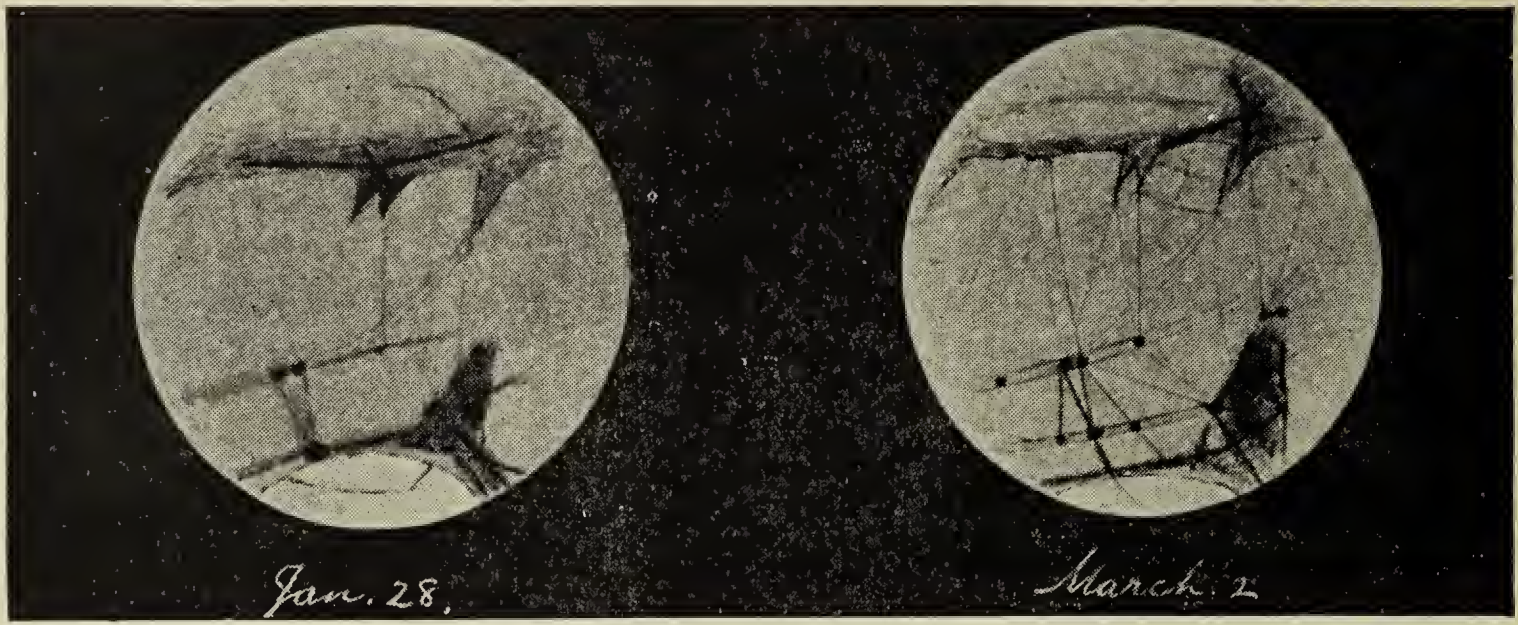
A diagram to show how the moon is eclipsed by the earth

An eclipse of the moon occurs when the earth passes between the moon and the sun in such a way as to cast a shadow on the lunar surface and thus cut off the light otherwise reflected back to us. The shadow here is cone-shaped, too, but it is so much larger that the whole moon may be eclipsed.

Although eclipses of the sun and moon have been observed from remotest antiquity, and were often believed to be associated with evil spirits and therefore to portend evil, we now know that they result wholly from coordinated movements of the cosmic bodies. So definite has our understanding of them become that astronomers can foretell their occurrence to the very minute two or three centuries hence.

Are There Other Worlds than Ours? This is the question asked by almost all students and others interested in the cosmic bodies. For the sake of satisfying curiosity, if nothing else, the writers wish they could answer this agelong question. But they cannot; neither can the astronomers. What is said, then, must wait for further confirmation.

So far as the solar system is concerned, there are probably but two planets,



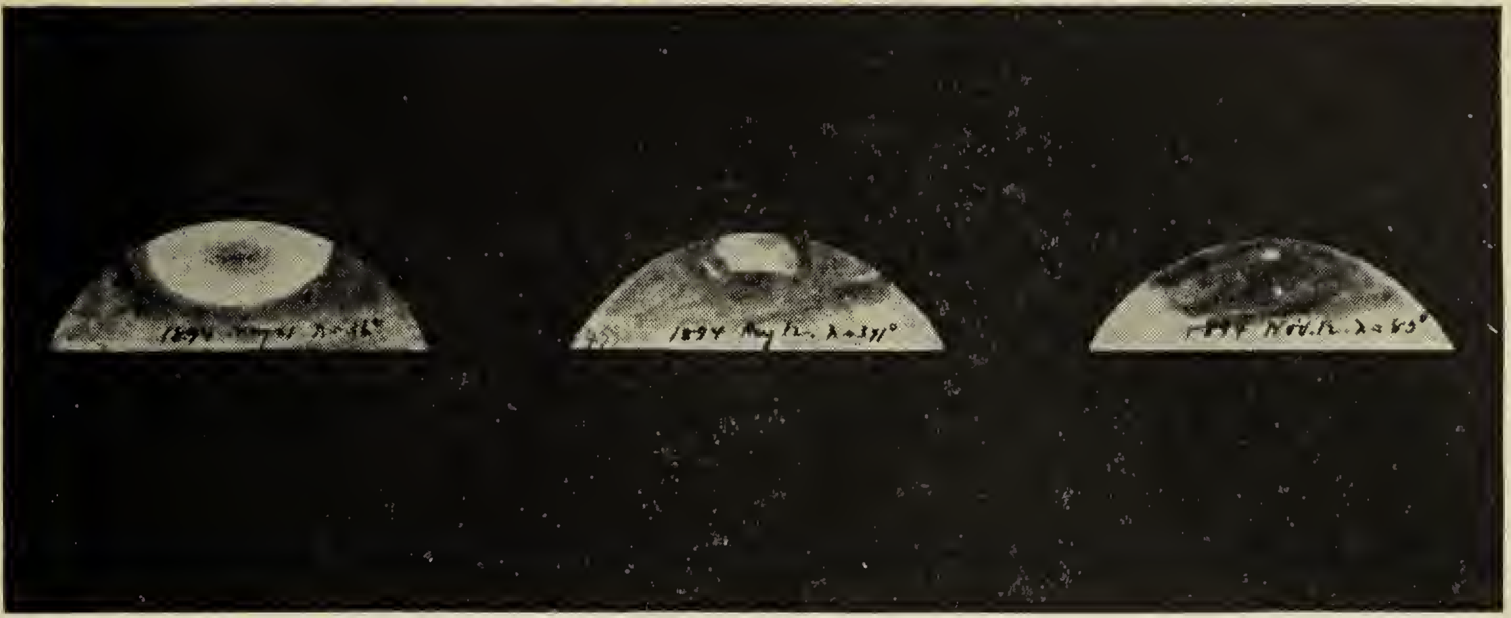
Lowell Observatory

Lowell's conception of the canals on Mars

aside from the earth itself, that could possibly support life. These are Venus and Mars. The others are either so close to the sun or so far away or have such unfavorable conditions in other respects that living forms as we know them could not exist.

Venus, being closer to the solar body than the earth, receives abundant light and heat to support life. Indeed, the temperature would probably be too high were it not for the shading effects of the ever-present clouds that seem to engulf its sphere. The question as to the length of its day, which has some bearing upon the probability of life there, has not been settled. The giant mists that envelop Venus never break away, and this makes the problem difficult even to attempt to study.

Mars is inclined to be clear, and recent investigations, despite its further distance from the sun, seem to indicate temperatures compatible with life. It is now believed that certain regions reach a temperature of possibly 40° or 50° F. Although this is not warm, many organisms could thrive under these conditions. The greatest objection seems to be the doubt as to whether enough atmosphere and water exist to support life. The late Dr. Lowell regarded conditions as favorable and even believed he could detect great irrigation systems to bring the polar waters down to the plains of lower latitude. These waters, he believed, were supplied by the white polar caps, which are known to advance and then to recede on Mars with annual periodicity. Lowell regarded the recession as being occasioned by melting snows which furnished water for the irrigation canals. But other investigators fail to find convincing evidence of such ingeniously devised systems. So here we find inference and personal opinion to be about the only reasons for suspecting the presence of life on this planet.



Yerkes Observatory

Polar caps on Mars

As to whether or not there are planetary families, where life could exist, accompanying other stars we have no evidence whatever. It is more than likely that the multiple stars do not have such families. Their mass is divided among the two or more bodies of the star group itself. But there appear to be many single stars too—billions of them, in fact. To most people it seems almost unthinkable that our solar system alone, among all the hosts of the heavens, is unique in this respect—that it stands alone, the only representative of its kind in the universe. Moreover, it is equally difficult to believe that the earth, out of so many, is the only celestial body where such an alchemy of physical and chemical substances developed as to generate life. That would be singular, indeed.

Nevertheless, disregarding the question of life, we have no ocular evidence of the existence, even, of other solar systems like our own. Perhaps we never shall have. For if one could be transported to Alpha Centauri, the star nearest the earth, after the sun, he would need a telescope a thousand times more powerful than the great Mount Wilson reflector to bring the giant Jupiter into view. That men will ever be able to make a telescope of such power seems, at the present, altogether improbable. However, in the light of the scientific surprises of the past, we shall be wiser to make no commitments. *It is hazardous to set arbitrary bounds to the possibilities of science.*

Questions for Study

1. What evidence can you present to support the belief that the sun and its planets came from a single presolar body?
2. How would you define a hypothesis?

3. Why are the different tentative proposals that have been advanced to explain the origin of the solar system called *hypotheses* rather than *theories*?

4. What hypothesis regarding the origin of the solar system seems most plausible to you? Why?

5. How are the spatial relationships among the bodies comprising the solar system believed to be maintained?

6. Why are the stars in our galaxy believed to weave in and out among one another "like bees in a swarm"?

7. Why, in your judgment, would it be impossible for the stars near the outer edge of our galaxy to wander indefinitely out into space like the molecules of a diffusing gas?

8. How would you explain the seasonal cycles?

9. How are eclipses of the moon produced?

10. How are eclipses of the sun produced?

11. Do eclipses of the sun occur during the dark or the light phase of the moon?

12. Do eclipses of the moon occur during the light or the dark phase of the moon?

13. In what ways is your daily life affected by the force of gravity?

14. How do the laws of motion affect your daily life?

15. What is your opinion regarding the possibility of there being life on celestial bodies outside our solar system?

16. It has been suggested that sunspot frequency may govern the periodic swing of the stock market by influencing people to invest freely at one period and to be more cautious and conservative at another. What would be your attitude toward this suggestion?

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CHAPTER EIGHT

Superstitions regarding Comets and Meteors Have Been Displaced by Scientific Knowledge

Comets Were Once Considered to Be Bad Omens. Comets, with their curious, luminous tails, have been known for centuries. They had been observed long before the Christian Era began. For the most part they were regarded as precursors of evil and disaster. This sentiment was so widespread among the ancients that it finds frequent expression in their literature. Homer in his Iliad has Achilles describe his helmet as being

> Like the red star, that from his flaming hair
> Shakes down disease, pestilence, and war.

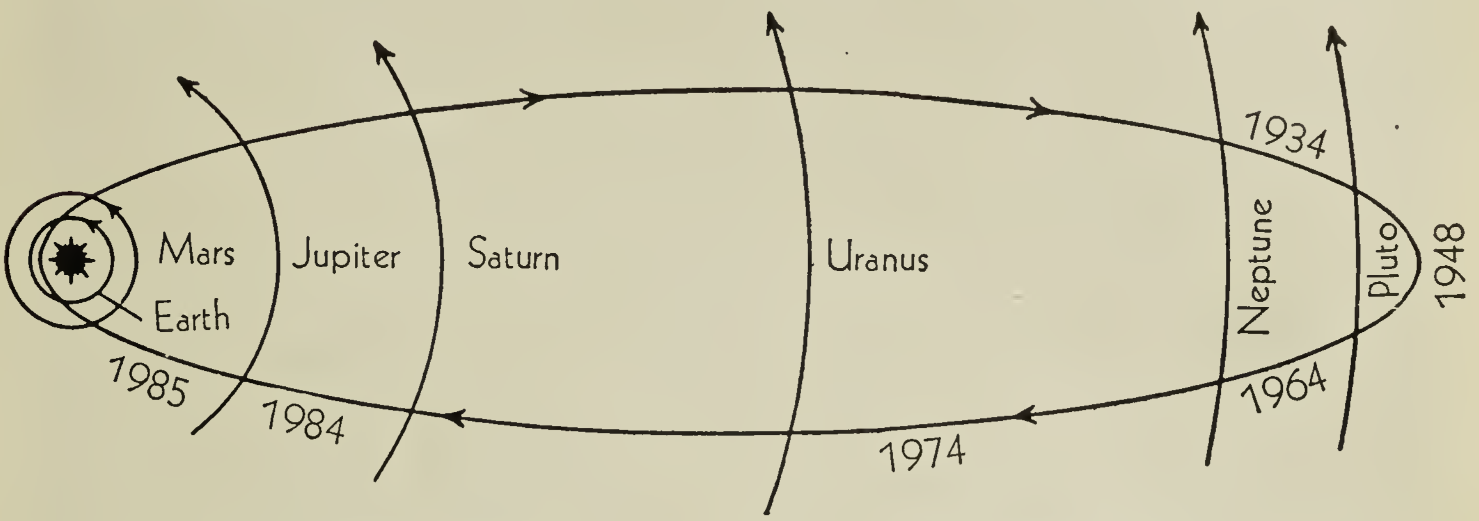
A collection of doggerel rhymes compiled as late as the seventeenth century contains the following:

> Eight things there be a comet brings,
>   When it on high doth horrid rage;
> Wind, Famine, Plague, and Death to Kings,
>   War, Earthquakes, Floods, and Direful Change.

Indeed, comets continued to be held in this superstitious awe until the dawn of the scientific age, when Kepler worked out the orbits of some of them and pronounced them not "eternal" but made of changing matter.

Comets Frequently Appear in Space. Comets are much more numerous than most people suppose. On an average about five comets swing through the curved end of their orbit about the sun yearly. In 1925, the banner year, eleven were observed; in 1927 ten were counted. However, on an average but one of these each year is bright enough to be seen with the unaided eye. In fact, with the exception of the very brightest comets, a person would have to be looking around through the heavens rather sharply to discover even this visible one. Nevertheless, owing to the length of time that they have been studied, the orbits of approximately four hundred comets are known with varying degrees of accuracy.

Comets Move in Regular Orbits. We commonly think of comets as having a head accompanied by a long, fiery tail. This shape is assumed only during the period of their close proximity to the sun. At such times the head presents a sort of hazy, globular coma within which is usually found a brighter spot called the nucleus. This starlike nucleus is sometimes very brilliant, approaching that of a star of the first magnitude. The average diameter of the coma is about 80,000 miles, but the Great Comet of 1811 is said to have had a coma 1,000,000 miles across.

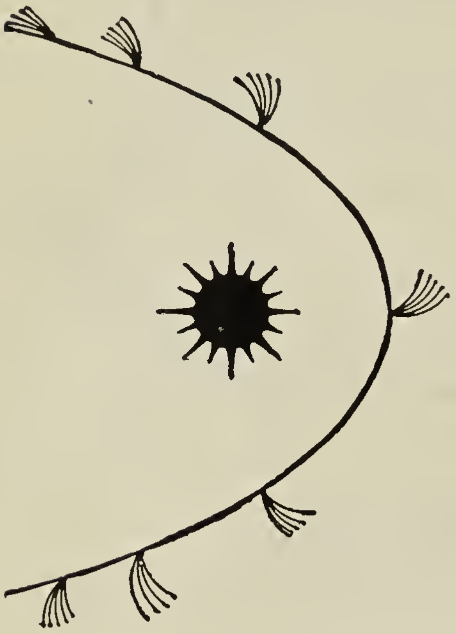


The orbit of Halley's comet drawn approximately to scale

Note the relative slowness of its movement when passing through the outer curve of its orbit

The tail does not begin to form until the comet reaches a point somewhere near 200,000,000 miles from the sun. It is usually about this time that the comet is detected by observers. As it approaches the solar body, usually great agitation takes place in the head. It contracts. What appear to be great concentric ringlike jets pass outward in all directions, but on the side next to the sun they are repelled and driven back through the head, where, uniting with the portions of the rings on the side opposite the sun, they are swept back to form the growing tail, which stretches out to enormous lengths. When connected with a large comet, the tail may develop to cover an arc of 50° and may reach a maximum length of 150,000,000 miles or more. At the farther end the tail may spread out fan-shaped to a width of from 5,000,000 to 10,000,000 miles. In this condition a comet is one of the most gorgeous objects to be found in all the heavens. It is in volume also one of the largest, being surpassed only by the great nebulae and certain young, giant stars.

The tail generally reaches its maximum length just before and just after the comet passes perihelion. Strange to say, too, the tail always stretches out on the side opposite the sun. Thus it follows the head as it approaches the sun, but extends on in advance of it as the comet recedes from the sun. It is not known with certainty just what this tail is. It is believed to be made up of tiny particles of what is perhaps solid and gaseous matter driven off from the tenuous materials that form the head. Ordinarily the sun would attract small objects to it, but these particles are so tiny that the repellent force of the light rays decidedly overbalances the pull of the sun's gravitation; so they are driven out violently on the far side of the comet. This expelled matter is then made luminescent by the action of the sunlight and presents the glorious spectacle of a long, fiery banner.



Relation of the tail of a comet to the sun

Note that the tail is always directed away from the sun

What Is a Comet? We now come to a difficult question that has received much attention by astronomers. A good deal is known as to what comets are *not*, but not so much is known definitely as to just what they are. In general, they are believed to be a swarm of relatively small bodies of some sort. These are held together by their mutual attraction, although even then the particles, relatively speaking, are widely separated.

When the tail is formed by an approach to the sun, the material so driven out of the head can never be retrieved. Consequently the comet is reduced at each encounter with the solar body by just the mass of the matter expelled into the tail.

The mean density of comets must be extremely low. In fact, it must be thousands of times lower than the atmosphere of the earth at sea level. For this reason they are practically transparent. The passage of the head of a comet between an observer and a bright star does not dim the latter to any appreciable extent. It is fairly certain that the mass of no comet yet observed exceeds one one-hundred-thousandth that of the earth. Dr. Baker tells us that it has been estimated that the brightness of Halley's comet in 1910, if produced by reflected sunlight alone, could be accounted for on the supposition that each cubic mile of its volume contained but a dozen little bodies of cometary material no larger than small marbles. The tail of at least one comet is believed to have swept right across the earth without making a cosmic stir which was perceptible to the least degree.

Some Comets Disintegrate. Comets sometimes break up, and, in at least one instance, a comet has been known to disappear altogether. The head of Brooks's comet separated into four parts. Taylor's comet was actually observed to break into two in 1916. The most striking of all the comets in this respect was the well-known Biela's comet. It had a period of six and one-half years. When it appeared in 1846, it stretched out into an elongated form which later divided, each half assuming cometary features. When the twin comets appeared six and a half years later, in 1852, one had lagged behind the other as much as one and one-half million miles, and they alternated in brightness.

Yerkes Observatory

Brooks's comet

The telescope was kept focused on the comet. This caused the stars to appear as elongated objects

Since that time the comet has never been seen, although it should have appeared at least a dozen times in the interim.

"Shooting Stars" Are Meteors. Full cousins to the comets, astronomically speaking, are meteors and meteorites. These beautiful objects are commonly known as "shooting stars." They may range in size from that of a grain of sand to that of massive bodies weighing many tons. As a rule, however, they are very small. Perhaps most of them are not larger than a grain of wheat, and rarely do they reach the size of a hickory nut. As these bodies, pulled by the earth's gravity, fall in toward its surface, sooner or later they encounter its atmospheric shell. Being falling objects, the closer they come the faster they fall.

As the meteors strike our atmosphere, they meet with great resistance. Anyone who has ever tried to run against a strong wind knows something of the resistance that air exerts against a moving body. The resistance offered in this case, however, is hardly to be compared with that which flying meteors encounter. The friction is so great that the surface of the meteor is quickly

This corkscrew path was made by a meteor passing through the atmosphere

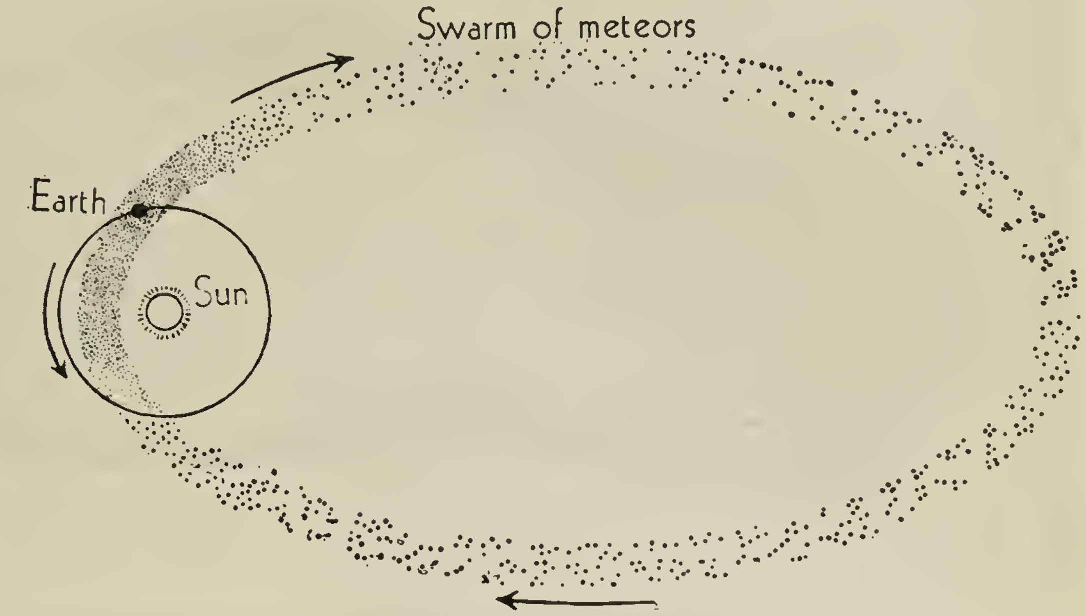
heated red-hot. It is at this instant that the "shooting star" flashes into view. By this time the outer surface has become so hot that incandescent particles of gasified and solid matter begin to crack and fly off. It is this heat-expelled material that forms the peculiar fiery tail. Because of their diminutive size most meteors soon "burn out" and disappear. For this reason we observe them as mere flashes of light.

Sometimes a meteor heads toward the earth and is so large that, despite the diminishing frictional effect of the air, it passes entirely through the atmosphere and lands on the earth. A visitor of this type is called a meteorite. Meteorites hold such interest and are so striking in their effect that we shall consider them more fully later. For the present we shall continue to discuss both under the general term *meteors.*

Where Do Meteors Come From? Once again we must say that astronomers are not certain; it is not known just where meteors come from. It has been suggested that they are planetesimals and aggregates of planetesimals still being gathered in by the planets and their satellites from the original bolts shot out from the presolar mass. In other words, the idea is that there are still some planetesimals left in the spiral arms from which the planetary family developed and that the earth is still growing a little by pulling these in. Other students of the problem have held that they are wanderers from interstellar space—free lances, as it were, traveling around without restraint from the larger cosmic bodies. Moving in their course, they pass so close to the earth that they are drawn in by its gravitational pull. Finally there are several astronomers who believe that meteors are the remains of disrupted and disintegrated comets.

Although an occasional meteor may be seen any night, yet it is a well-known fact that meteors tend to move in periodic showers. The brilliant manifestations that appear at intervals of a number of years, such as the Andromids or the Leonids, take place when the orbit of the earth happens to intersect a stream of meteors at its densest point.

If these streams should be produced by the disintegration of comets, one would expect the meteors to follow courses comparable to those of the cometary orbits. We find that they are apparently inclined to go in elongated, elliptical orbits similar to those traveled by comets. The Perseids, or August meteors, move in practically the same orbit as that of Tuttle's comet and the Leonids, or November meteors, in that of Tempel's comet. Perhaps the strongest evidence, however, supporting this source of origin, for at least a part of the meteors, is to be found in the case of the Andromids. The orbit of this meteoric stream coincides almost exactly with the path of Biela's comet, which, as has already been stated, disintegrated and apparently disappeared in 1852.



How old comet trails are believed to cause meteoric showers [1]

Meteors Are Very Numerous. The casual observer has little idea of the number of meteors that enter the earth's atmosphere daily. Moreover, for the most part just those that fall on a clear night can be observed; and finally "shooting stars" are seen only when one happens to be looking in the direction in which they appear. If the sky were always dark and clear, it is estimated that at least 20,000,000 meteors would be visible in the earth's total atmosphere every twenty-four hours.

When one contemplates a number like this, he is thankful that most meteors are mere specks of matter, and is grateful also for the presence of an atmosphere, which acts like a great net protecting us otherwise helpless human beings on the earth.

Meteorites Are Numerous and Their Composition Varies. It is very unusual for one of these visitors from space to be able to resist the effect of friction with the atmosphere to the point of reaching the earth. Consequently the number of meteorites as compared with the total number of meteors is relatively small. Sometimes they appear to fall in a swarm, pitting the soil where they land, much like the pattern of a shotgun charge. This effect, however, is not produced by a group of meteorites that started into the

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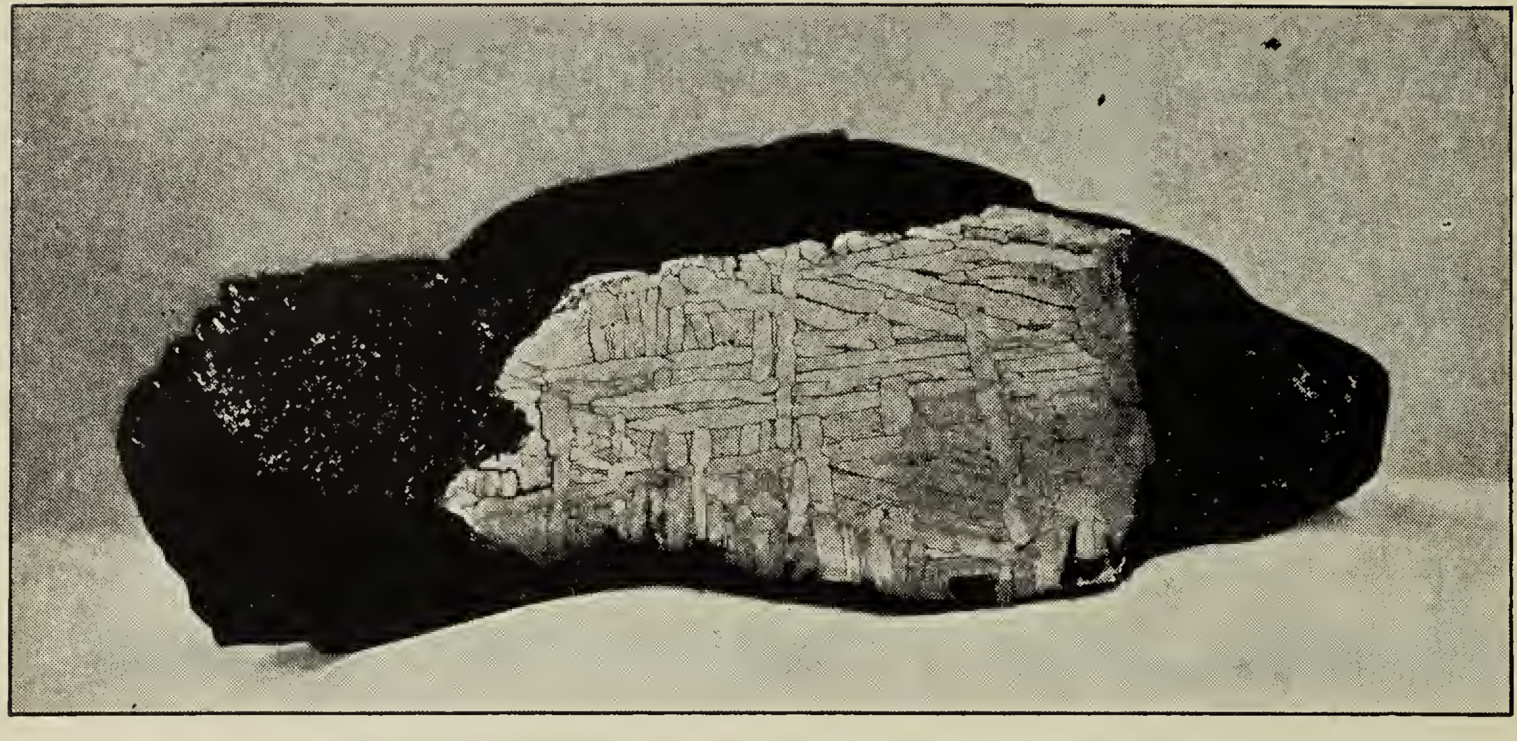
[1] From *The Outline of Science*, by J. A. Thomson. By permission of George Newnes, Ltd.



A polished, etched surface of an iron-nickel meteorite

earth's atmosphere as such. It is probable rather that the meteorite came in as a single body with such velocity as literally to dash itself to pieces against the air with which it collided. In this way thousands of small meteorites may be shattered out of a single one.

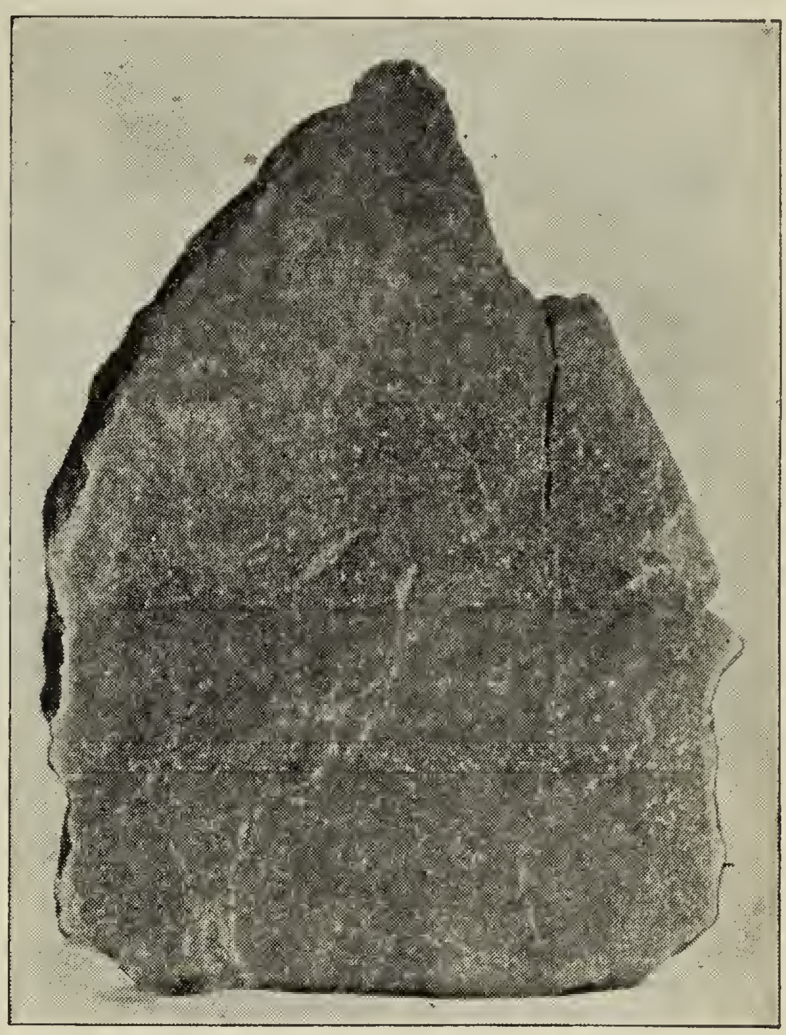
In respect to composition meteorites may be classified as of two general classes, the iron and the stone. As one would expect, there are all degrees of gradation between these two extremes. Iron meteorites are formed from iron combined with from 5 to 25 per cent of nickel. Sometimes compounds of these metals are also present. Naturally they are very heavy, and their structure is peculiarly characteristic. Whenever the smoothed surface of an iron-nickel meteorite is etched with dilute acid, a striking and unique pattern of parallel bars is brought out. The bar aggregates may occupy positions at various angles with one another. The whole effect produced is an unfailing means of identification.

The stony meteorites are naturally much lighter both in color and in weight. For the most part they are silicate minerals, together with minor amounts of metallic alloys and sulfides. Internally they are a sort of dirty gray or brown, and are formed from crystals held together by a cementing matrix, giving the whole a granular appearance.

Although meteorites cannot be said to be of common occurrence, they are much more abundant than was formerly supposed. Specimens have been found in Texas, Oklahoma, Kansas, Missouri, Nebraska, South Dakota, Wyoming, New Mexico, Colorado, and Utah.

Great interest has always been manifested by scientists in the chemical and physical properties of meteorites. These are the only material visitors that descend upon the earth from outer space. Consequently men are eager to learn just what kind of story they bring. Altogether upward of thirty different chemical elements have been found in meteorites and in their occluded gases. The ones that have been determined so far have all been common to those which are found either in the earth or in its atmosphere. This is perhaps the most tangible evidence man possesses as to the identity of all cosmic matter.

Some Very Large Meteorites Are Known. Most of the meteorites, of course, fall into the oceans, because of the more extensive water area. The late Professor C. A. Young estimated that the total annual amount of meteoric matter reaching the earth averages about 36,500 tons. This includes both meteors whose gasified material is added to the atmosphere and the solid bodies of meteorites. In a few instances very large meteorites have been discovered on the land. Some of these have been transferred to famous museums, and others still lie intact where they fell.

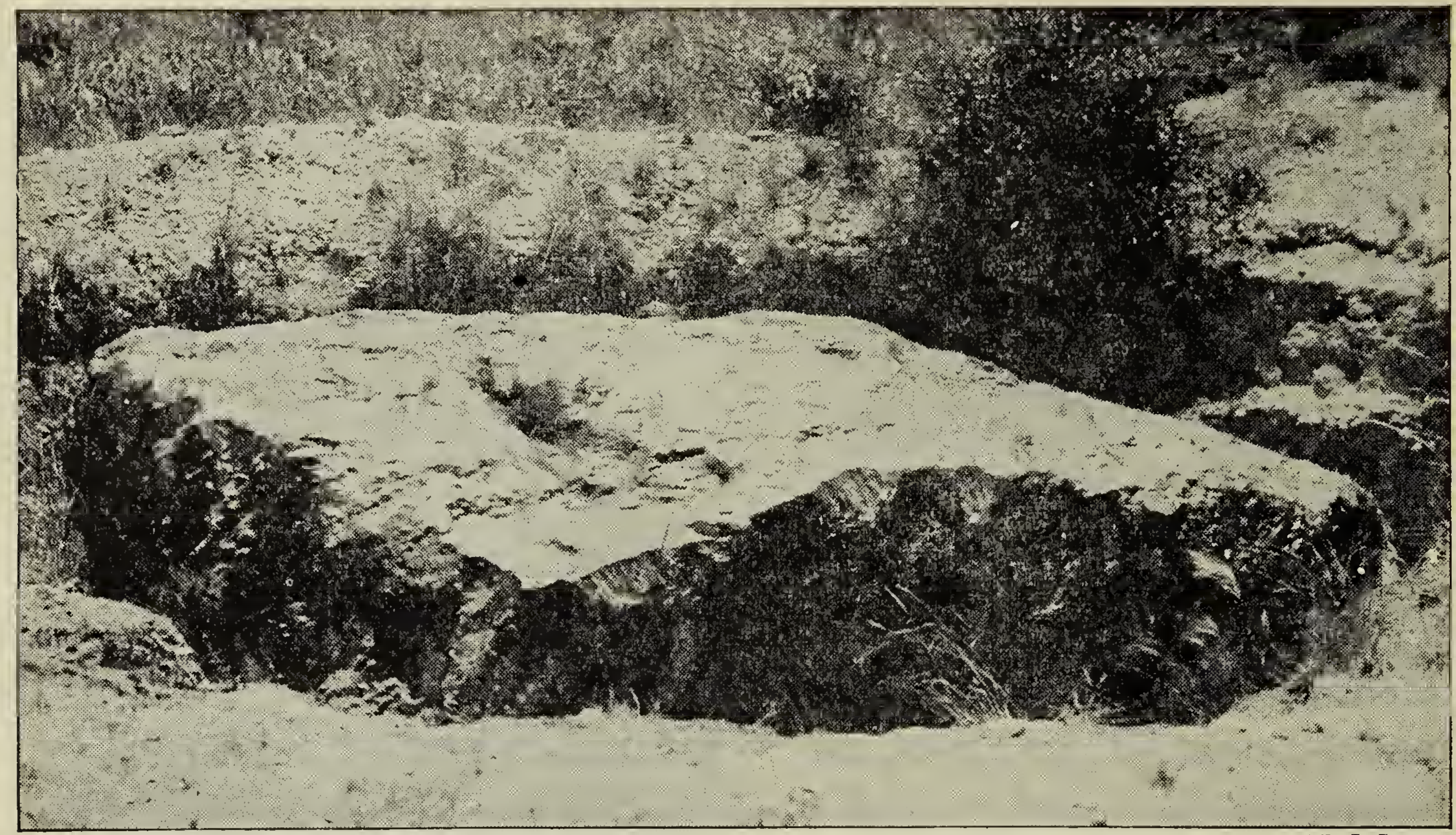


A polished, etched surface of a stony meteorite

The small flakes in the surface are crystals of nickel

One of the largest meteorites known still lies where it fell in Southwest Africa. It weighs more than fifty tons, which is probably the reason why it has not been moved to some museum. It is more than likely that some day it will be added to some famous collection. Another noted one is the Cape York meteorite, discovered by Admiral Peary near Cape York, Greenland, in 1895. It weighs twenty-six and a half tons. It is a dense mass of iron and nickel, seven feet high, five feet wide, and almost seven feet long. It is now on display as the chief representative in the collection of the American Museum of Natural History in New York. This collection also contains the Willamette meteorite, a well-known one discovered in Oregon.

Effects Which Were Produced by Two Historic Meteorites. One of the two most famous meteoric effects produced in the world is in northeastern Arizona near the Canyon Diablo. It exists as a great crater in an otherwise



W. J. Luyten

Grootfontein meteorite

One of the largest known meteorites

monotonous desert region. This gigantic depression is 4200 feet in diameter and 570 feet deep, and the rim rises 160 feet above the surrounding plain. Because of its elevated rim and before its origin was suspected, the crater was called Coon Butte. Since its genesis has been fairly well worked out, it has been named Meteor Crater. If this great excavation was made by a single meteorite, it must have been a mammoth of huge dimensions which struck the plain as it came in obliquely from the northeast. Dr. Olivier, who is one of our best authorities on comets and meteors, is inclined to believe that the whole head of a comet collided with the earth at this point. Several tons of small meteoric iron fragments have been picked up within a radius of six miles.

By the force of the crash the rocks below the floor of the crater have been crushed to a depth of more than a hundred feet and look as if they had been heated to a high temperature. Millions of tons of rocks have been displaced outward to help to form the rim of the crater. The larger of these rocks are estimated to weigh as much as seven hundred tons.

Many futile attempts to locate the main body of the meteorite have been made. But it is now believed that the tremendous heat generated by its impact with the earth exploded the meteorite, forming the existing crater and scattering debris far and wide. On the basis of the scattered remnants, it has been estimated that about 90 per cent of the body should have been iron or iron oxide.

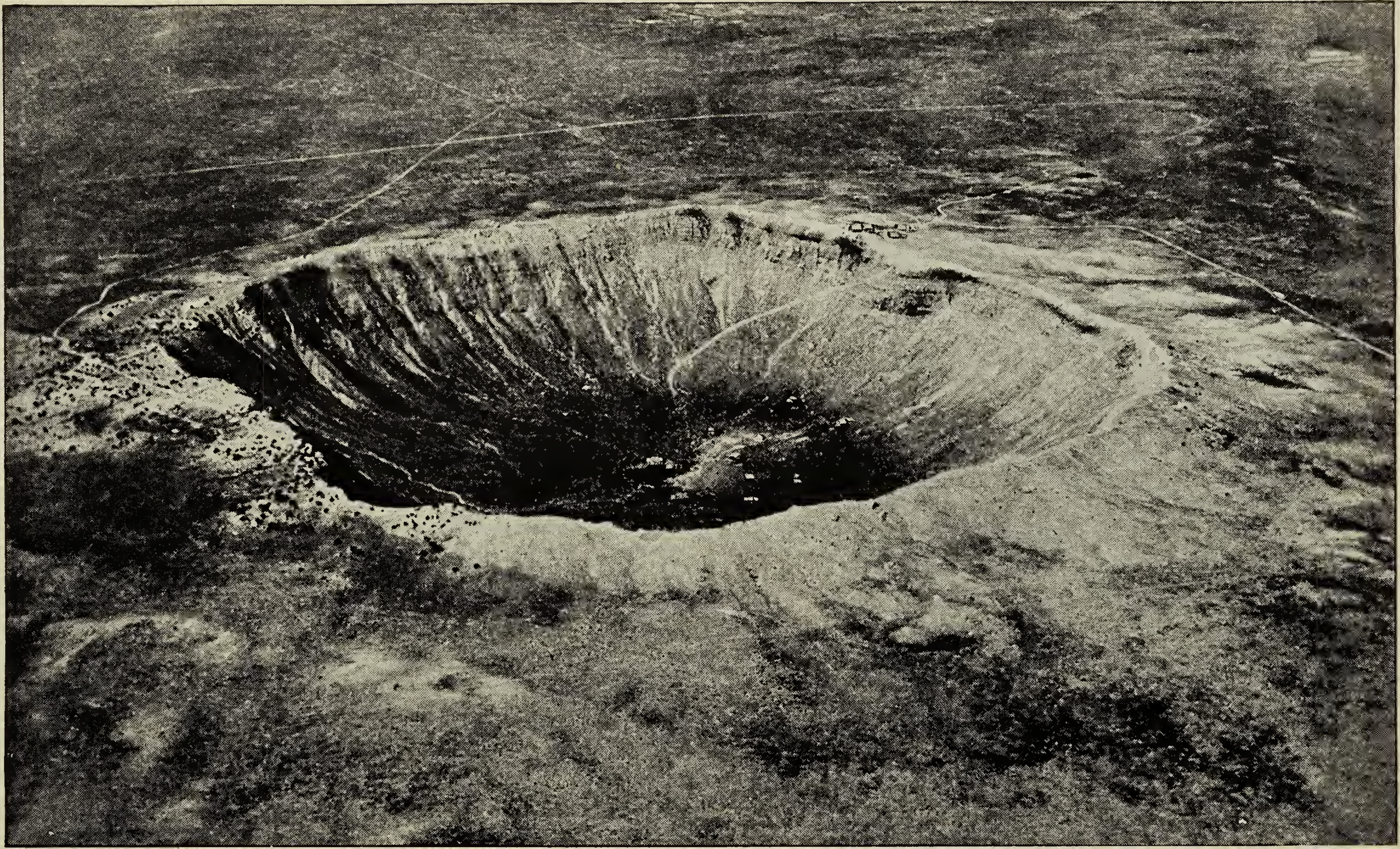
American Museum of Natural History

Willamette meteorite

Conical base of weathered iron

When this great catastrophe occurred can only be estimated. It could not have been less than seven hundred years ago because trees of that age are found growing on the side of the crater's rim. It may be significant that the Navaho Indians of that region have a legend to the effect that fire fell from heaven a long time ago and destroyed certain members of their tribe.

Though the Arizona meteorite was a mammoth one, the most imposing meteoric fall took place in a densely forested region in the north-central part of Siberia in 1908. An area with a radius of from twenty to thirty miles was completely devastated. The trees with their branches barked and torn lay pointing outward from the center in all directions. This wide area of destruction is believed to have been caused by an immense bubblelike envelope of hot gas which the meteorite carried down with it. At Vanovara, fifty miles away, a wave of hot air hurled a man several feet from the steps of his house, where he was sitting. At Kerensk and Ilimsk, two hundred and fifty miles from the scene of the impact, great detonations resembling thunder were heard, and pillars of smoke and flashes of fire were seen. At Kansk, four hundred miles away, railroad men felt the air wave and heard a reverberating sound. The seismographs at Irkutsk, nine hundred miles away, registered the earth tremors set up by the encounter. Since it took place in a very sparsely settled district, no one seems to have been killed. However, a herd of reindeer,



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Panorama of Meteor Crater, Canyon Diablo, Arizona estimated at fifteen hundred, grazing near that spot were reported to have been totally annihilated. Only a few scorched carcasses remained as silent witnesses of the deadly catastrophe.

Questions for Study

1. In reality how do stars and "shooting stars" compare?

2. Why do the tails of comets appear only when the comet is near the sun?

3. Why are the tails of comets always on the side opposite the sun?

4. How would the hazard of being struck by a meteorite on Mars probably compare with the hazard of being struck by a meteorite on an equal area of the earth's surface?

5. How do you suppose that the frequency of *meteorites* over equal areas of the moon's surface and the earth's surface compare? Why?

6. What evidence presented by meteorites supports the idea that all celestial bodies are composed of the same kinds of elements?

7. What is probably the best theory yet advanced as to the cause of periodic meteoric showers?

8. Why do the larger meteorites often break into pieces by explosion as they approach the earth?

9. Why do you suppose that comets came to be associated in the minds of the ancients with calamities and disasters?

10. Why has it been possible for modern man to free himself largely from superstitions regarding comets and meteors?

11. How has man's conception of the cosmos been affected by the development of astronomical science?

12. What effect is astronomical development having upon astrology?

13. How has the growing knowledge of the heavens contributed to man's feeling of security?

14. Can you think of any ways in which man's religious views may have been affected by his changed conception regarding the nature and extent of the cosmos?

15. What effect is man's growing knowledge of the heavens having upon his attitude toward the scientific method as a way of arriving at dependable truth?

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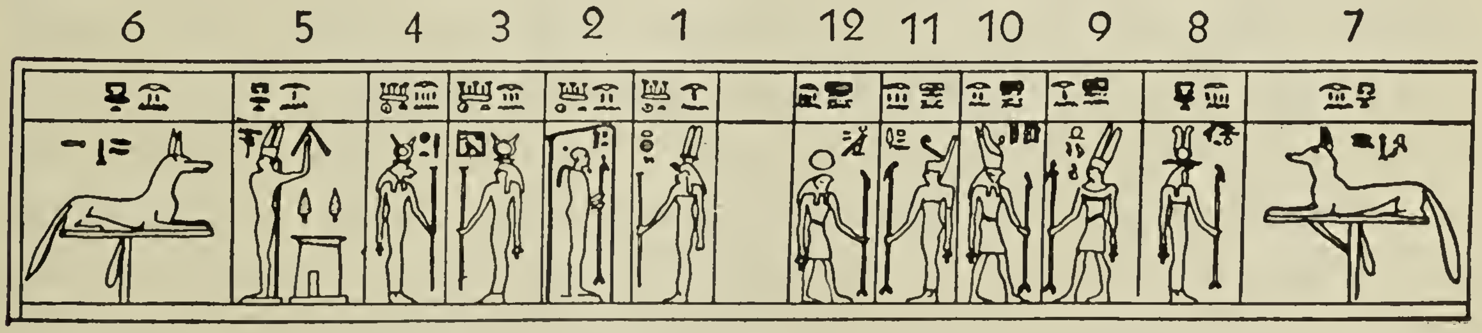
CHAPTER NINE

Astronomical Bodies Enable Man to Determine Time

Primitive Man Had Crude Ways of Reckoning Time. The first and most natural unit of time to challenge the attention of early peoples was doubtless the day. Its length was determined by the apparent movement of the giant time clock of the skies, the sun. But days follow one another in rapid succession. So in many cases it was difficult to remember the number of such periods that had elapsed between two events. If the time was long, this unit, therefore, was not very helpful. Naturally, man sought a more helpful timepiece and likewise found it in the sky.

Early peoples noted that the moon passed through its phases periodically, and that this cycle was completed in about twenty-eight days. Consequently they began to space longer periods by the moon. Events for them were related by so many moons, or they agreed to perform certain duties so many moons in the future. This was the favorite scheme used by the American Indian in reckoning time; and our modern month has the moon's periodicity as its basis.

But the lunar month was found too short for expressing the longer durations of time. Convenience demanded a larger unit, and again the apparent movement of an astronomical body served as the criterion. The Egyptian people were located not far north of the equator. There the morning sun in the summertime rises almost out of the due east and climbs majestically into the heavens. Moreover, the whole economic life of this ancient people was built around the annual floods of the Nile, which brought moisture and



Month table at Rameseum, Karnak, Egypt

The calendar of the Egyptians[1]

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[1] From *The Dawn of Astronomy*, by Sir J. Norman Lockyer. By permission of Macmillan & Co., Ltd.

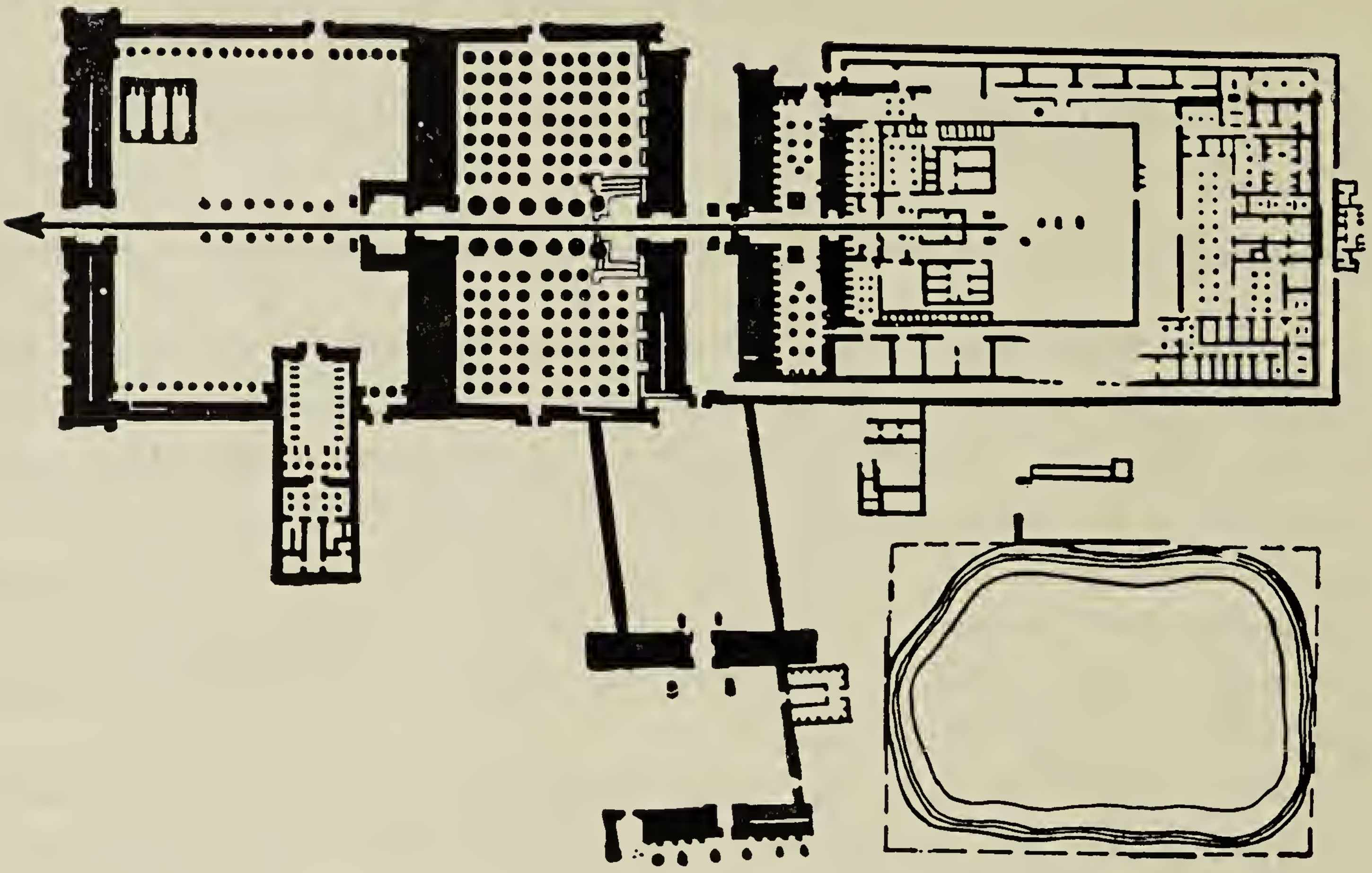

Diagram of the temple of Amen-Ra

The arrow points to the place of sunset at the summer solstice [1]

fertility to their fields. It became of great importance, then, to be able to foretell with some accuracy when this event would occur in order that they might plan their social, commercial, and agricultural activities. Now the Egyptians had noted a significant seasonal change in the appearance of the stars. They had observed that every spring, just about the time that the Nile flood began to make its appearance, a certain very bright star arose just ahead of the sun. For them, then, this star became the messenger that foretold the flooding of the Nile valley. Consequently they named it the Announcer. We know this star today as Sirius, the Dog Star.

A more accurate observation as to the length of the year was that of the apparent movement of the sun northward in the spring and early summer. At a certain point on the sky line each year this progress stopped, and the sun began to retrace its course southward. This date for the Egyptians thus became an important base line for reckoning time. Indeed, at Karnak, the great temple of Amen-Ra, the sun-god, is so turned that its main axis points directly to the point on the horizon where the sun sets on the longest day of the year. By counting, these people found that about 365 days intervened between two of these consecutive summer solstices.

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[1] From *The Dawn of Astronomy*, by Sir J. Norman Lockyer. By permission of Macmillan & Co., Ltd.

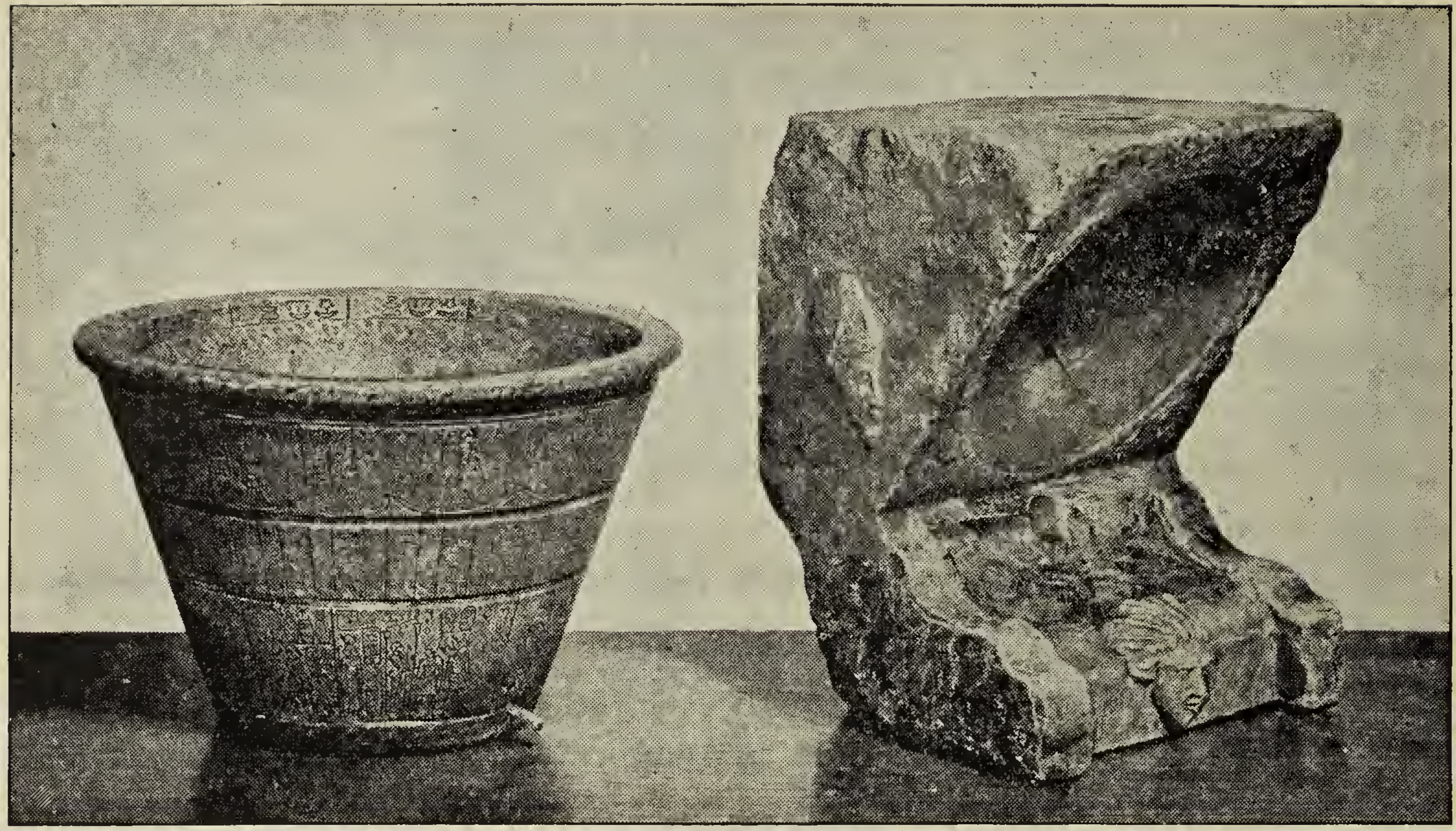
Today we recognize this occurrence not as marking a true movement of the sun, but as indicating a complete circuit of the earth in its orbit around the solar body. So here, again, our unit of time is based upon astronomical behavior.

Methods of Measuring Time Have Been Greatly Improved. When we come to more modern practices in time-reckoning, we find that, like the ancients, we are still almost wholly dependent on the movement of astronomical bodies. More than that, we are likely to take our present system in a matter-of-fact way, with little appreciation of the difficulties that had to be overcome in perfecting it.

In most countries previous to 1878 time was measured in the same terms as those adopted by their capital cities. Thus England adopted the time of Greenwich, a borough of Metropolitan London; France used Paris time; and other countries used the time of their capital cities. Within relatively small countries this plan worked with little inconvenience. But in large countries, like the United States and Canada, serious difficulties were encountered. With such great longitudinal differences as exist in the United States, the people of San Francisco, for instance, would find it practically impossible to use Washington, D.C., time. This difficulty was greatly enhanced by the advent of railroads, with their multitudinous train schedules and timetables. Different roads frequently made their own time system, which made the situation quite intolerable for the long-distance traveler.

The World for the Most Part Has Adopted Standard Time. In 1878 Sandford Fleming, a Canadian, in order to clear up this confusion, proposed a plan for a *standard-time* system. By the use of standard time, which was adopted by almost all countries at an international conference held in Washington, D. C., in 1884, the popular confusion resulting from movement east and west is avoided. By this scheme, the earth is divided longitudinally into twenty-four zones, each 15° in width and each representing one hour of time. Greenwich, England, is considered to be the starting point, and its meridian is known as the *prime meridian.* Since the earth rotates in a west-to-east direction, the first time meridian is located 15° west of Greenwich out in the Atlantic Ocean. The meridians continue thus on around the earth. They are numbered, however, both east and west from the prime meridian, thus giving both east and west longitude up to 180°.

For an equal number of degrees both east and west of the 15° west meridian, then (or, to be more specific, from the 7½° west meridian to the 22½° west meridian) by standard time, it is one hour earlier than at Greenwich. From the 22½° west meridian to the 37½° west meridian it is two hours earlier than at



L. C. Eichner

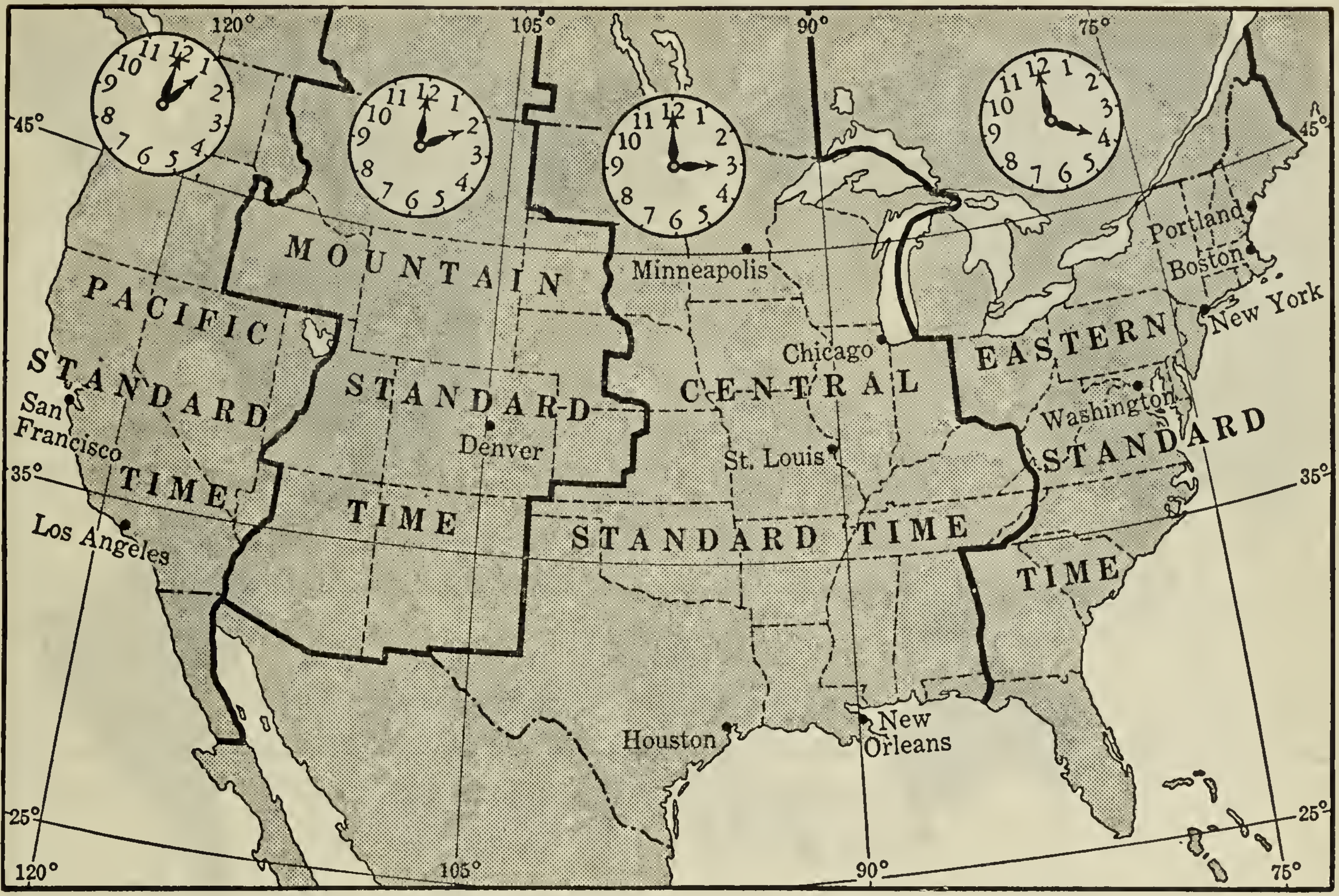
Instruments used by the ancients to measure time

Left, an Egyptian water clock, 1450–380 B.C. The unit of time measured is the time required for the bowl to empty its contents through the small drain at the bottom. Right, a Greek hemicycle, 350 B.C. By this device time is indicated by the movement of the shadow in the bowl as the sun crosses the zenith

Greenwich, and so on west to the 180° meridian. Thus New York City lies in the fifth time zone west from Greenwich. Hence it is always five hours earlier at New York than it is at Greenwich. San Francisco lies in the eighth time zone west; so it is always three hours earlier there than at New York and eight hours earlier than at Greenwich. On the other hand, points east of Greenwich have later time. Bombay, India, is in the fifth zone east; hence, when it is twelve o'clock noon at Greenwich, it is five o'clock in the afternoon of the same day at Bombay.

Travelers who go from one time zone to another have to adjust their timepieces accordingly. Those going west subtract the appropriate number of hours, and those traveling east add the proper number of hours, to get the correct time for their particular zone.

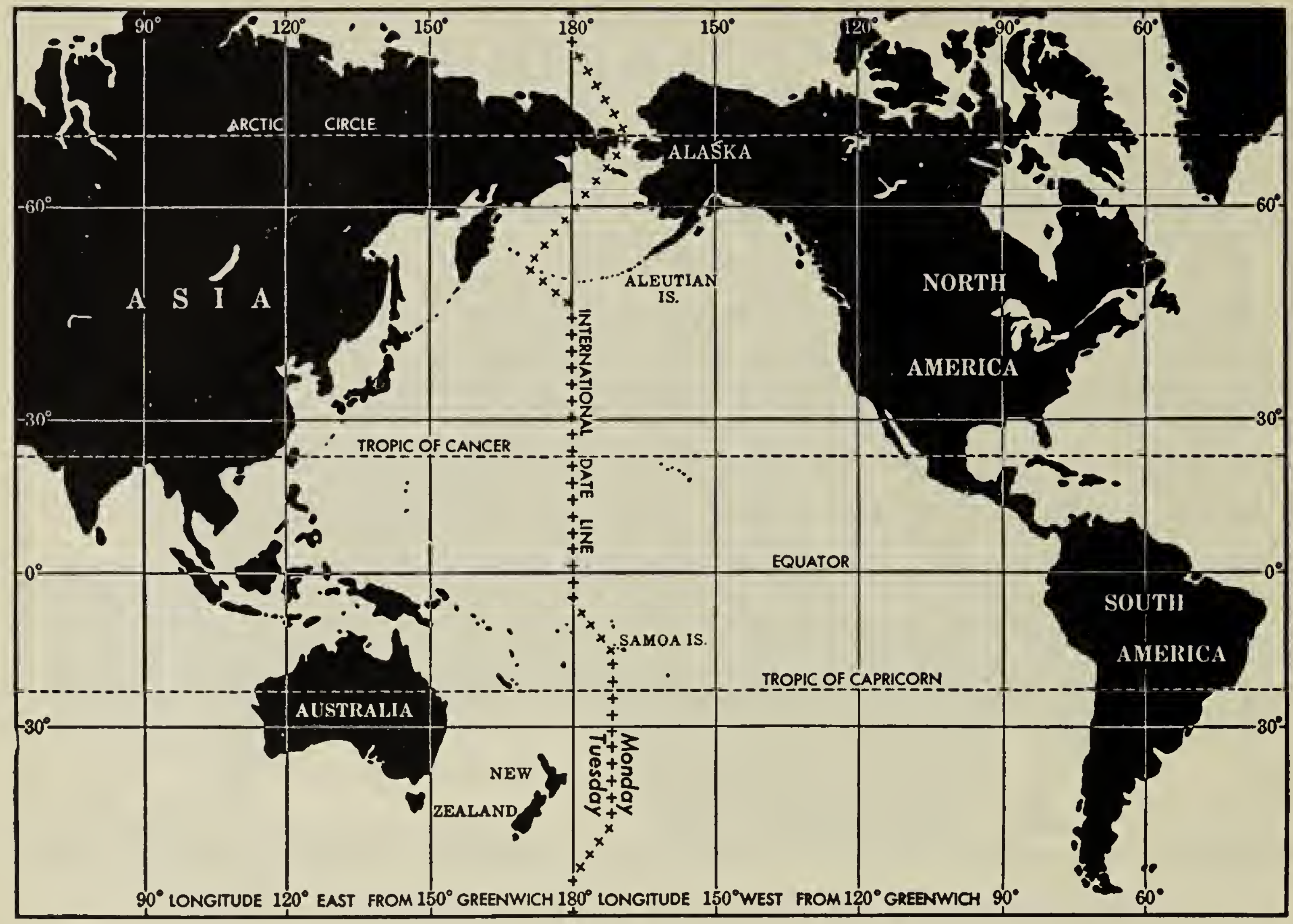
In considering standard time, one should always remember that the different time meridians do not mark the lateral boundaries of their zones. On the contrary, each meridian marks the approximate center of its time zone, so that the time at that point extends $7\frac{1}{2}$° both west and east of that meridian. To be specific, time meridian 105° west is located just a few miles west of Denver, Colorado, and locates the Mountain standard-time zone. This time zone however, extends both east and west of Denver for several hundred, miles.


PACIFIC STANDARD TIME
MOUNTAIN STANDARD TIME
CENTRAL STANDARD TIME
EASTERN STANDARD TIME
San Francisco
Los Angeles
Denver
Minneapolis
Chicago
St. Louis
Houston
New Orleans
Washington
New York
Boston
Portland
120°
105°
90°
75°
45°
35°
25°

Map showing time meridians and time zones in the United States

Strictly the boundaries of the different time zones should follow meridian lines straight north and south, but actually they do not. In the United States, for example, the time zones are determined almost wholly by railroad usage. It is most convenient for railroads to change time at the passenger division point nearest the true time line, for it is here that train crews are changed. Consequently the limits of time zones zigzag in a somewhat irregular way.

Greenwich Is Not on the International Date Line. One would naturally suppose, with the astronomical observatory at Greenwich marking the prime meridian, that calendar dates would change there, too. Here, again, convenience dictates otherwise. It would be very inconvenient for European peoples, for example, to have one date prevailing at Greenwich and a date one whole day earlier at Rome and Berlin, let us say. Consequently, by common agreement, the international date line has been located at the 180° meridian directly opposite Greenwich on the other side of the earth. This meridian falls near the middle of the Pacific Ocean and in this way avoids many complications and inconveniences that would result if the date line passed through populous land areas, such as England, France, and Spain. Like the time-zone boundaries, the international date line does not follow its meridian without deviation. It bends at several points to suit national convenience.


90°
120°
150°
180°
150°
120°
90°
60°
ARCTIC CIRCLE
ALASKA
60°
60°
ASIA
ALEUTIAN IS.
NORTH AMERICA
INTERNATIONAL DATE LINE
30°
30°
TROPIC OF CANCER
EQUATOR
0°
0°
SOUTH AMERICA
SAMOA IS.
TROPIC OF CAPRICORN
AUSTRALIA
30°
30°
NEW ZEALAND
Monday
Tuesday
90° LONGITUDE 120° EAST FROM 150° GREENWICH 180° LONGITUDE 150° WEST FROM 120° GREENWICH 90°
60°

The international date line

By this plan the calendar day changes, not when the sun crosses the international date line, but rather when it crosses the prime meridian at Greenwich. In this way the new day is made to begin at midnight, and this change in date progresses consecutively around the world as the earth rotates. Consequently the instant the change occurs at the international date line, it is just twelve o'clock noon of the previous day at Greenwich. Fifteen degrees east of the date line it is but 1 A.M. of the previous day. For this reason a ship sailing westward across the date line gains a day, while one sailing eastward loses a day, or, in the latter case, if the reader prefers, counts the same day twice.

Leap Year Is an Adjustment of the Calendar to Keep Pace with the Sun. It would have been most convenient had the period of revolution of the earth and the completion of its three hundred and sixty-fifth rotation coincided exactly in point of time. But they do not, and that fact has caused calendar-makers a great deal of trouble. Instead of completing its revolution from one vernal equinox to the next vernal equinox in 365 days, the period we use as the common year, the earth requires 365 days, 5 hours, 48 minutes, and about 46 seconds to complete it. Thus the earth requires almost one fourth of a day longer to circle the sun than is indicated by the calendar. This causes the latter to run ahead of the solar performance. The amount of discrepancy is almost one fourth of a day each year. Consequently, by the Gregorian calendar, which we use, every fourth year is lengthened one day to compensate for this error. This overdoes the correction, however, by 44 minutes and about 56 seconds for that period. So in order to make a further correction, only even century years divisible by 400 are counted as leap years. Thus there are but 97 leap years in four centuries instead of the expected 100. By this adjustment the disagreement between calendar time and tropical year time, as it is designated, is but 2 hours, 53 minutes, and 2 seconds in four hundred years. Our present calendar practice was adopted under the direction of Pope Gregory XIII in 1582. It has been suggested that a further correction be made by counting the year 4000 A.D. a *common year* and every multiple of this number thereafter. This would reduce the discrepancy to about one day in 20,000 years. Since the proposed correction lies so far in the future, however, we need not concern ourselves with it now, for possibly a more intelligent posterity may find an even better way to adjust the calendar.

Questions for Study

1. Why is the question of time an important one in human affairs?
2. What are the basic factors which determine time as measured on the earth?
3. What are some of the inconveniences that must have beset the ancients with their crude methods of telling time?
4. What are some of the modern services which we all enjoy that would be quite impossible without accurate methods of determining time?
5. Why do Chicago and Omaha, for instance, have the same time, although they are approximately five hundred miles apart in an east-and-west direction?
6. Why is the international date line at 180° of longitude from Greenwich rather than at Greenwich itself?

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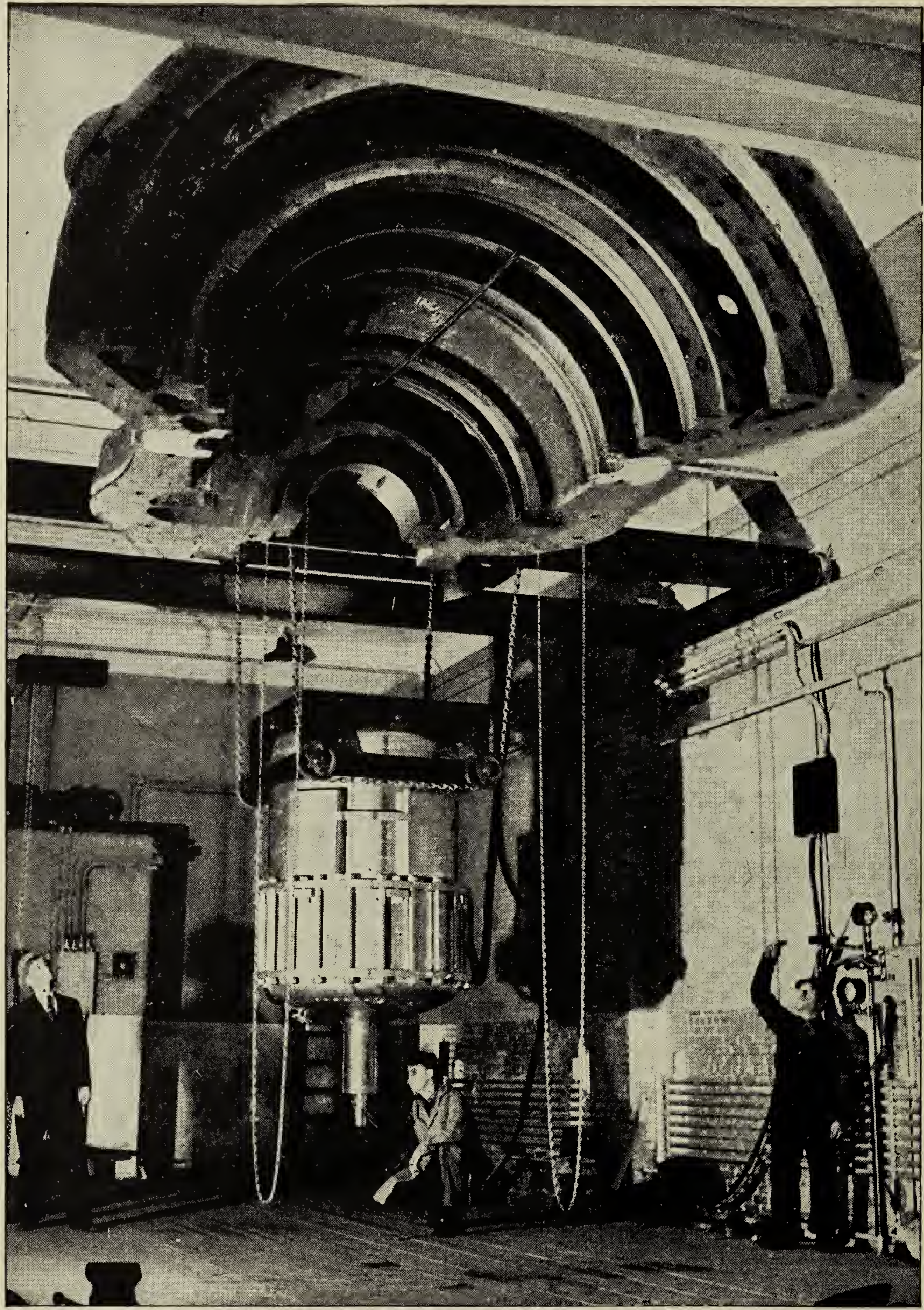
UNIT TWO

The Fundamental Distinction Formerly Supposed to Exist Between Matter and Energy Has Been Broken Down

The scientists of a half-century ago considered matter and energy to be two wholly separate and distinct entities. The most erudite physicist never even dreamed that the high wall erected between them by man's thinking could ever be broken down.

But one of the most surprising disclosures of modern times is that the forms of common matter and electrical energy are identical in nature. It would seem strange to speak of a rock or of a man's body as being composed of units of organized electricity. Yet apparently that now can be done with perfect propriety. The new physics, with its electrons, protons, neutrons, and positrons, reveals that matter and electrical energy are but manifestations of the same thing. An automobile standing at the curb is just as much a visible form of energy as it is of matter, and each is capable of being changed into the other. Physicists are now reporting the experimental transformation of matter into electricity. Indeed, the question has been asked whether large amounts of power from this source may but await the touch of a master hand and a new technique of transformation.

In this unit it will be our purpose not only to trace some of the thrilling discoveries by which this fundamental unification of matter and energy has been accomplished, but also to present the modern picture of the atom and some of its implications.



Research Laboratory of General Electric Company

A huge turbine casting being lowered into place for X-raying by the million-volt X-ray machine

See page 143

CHAPTER TEN

Matter Is Considered to Be But a Special Form of Energy

Matter Was Formerly Considered to Be Distinct from Energy. During the eighteenth century physicists recognized three fundamental principles: matter, energy, and ether. The existence of the first two they never questioned, but as to the reality of the last they were not so sure. Their imagination required that there should be some kind of medium to carry the beams of light on their long journey from the torrid sun or distant stars. Try as they would, however, scientists have never been able to demonstrate the existence of ether. Consequently most physicists, like Einstein the mathematician, have come to discard ether and to attribute to space itself an energy-transmitting property.

Matter, on the other hand, was viewed by the physicists of the last century as the real substance of the universe. It had a respectable reputation of long standing; it could be divided, but not beyond a certain limit; it occupied space; it could be felt, weighed, and tasted. Who could question the existence of anything that came with such well-established credentials? As Heyl says:

> The conservative citizens of the domain of physics . . . always retained in their hearts a special feeling of respect for matter as the ultimate reality, the substance of things, whose existence permitted energy to be and without which energy would be but an empty name.[1]

This habit of looking upon matter as the substantial principle in the universe dates back to the ancient Greeks. In the philosophical excursions which they took into almost every corner of the imaginable universe, they considered also matter—its nature and characteristics. As Thomson tells us, they had noted that a stone could be divided and redivided into smaller parts, and that this might be continued until the particles were of the fineness of powder. Ultimately, reasoned the Greeks, a time would come when the limit of divisibility would be reached; a particle so small would be obtained that it could not be divided further without destroying it. This particle they called the *atom*, meaning "something which cannot be cut."

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[1] Paul R. Heyl, *New Frontiers of Physics*, p. 70. By permission, D. Appleton-Century Company, Inc., publishers.

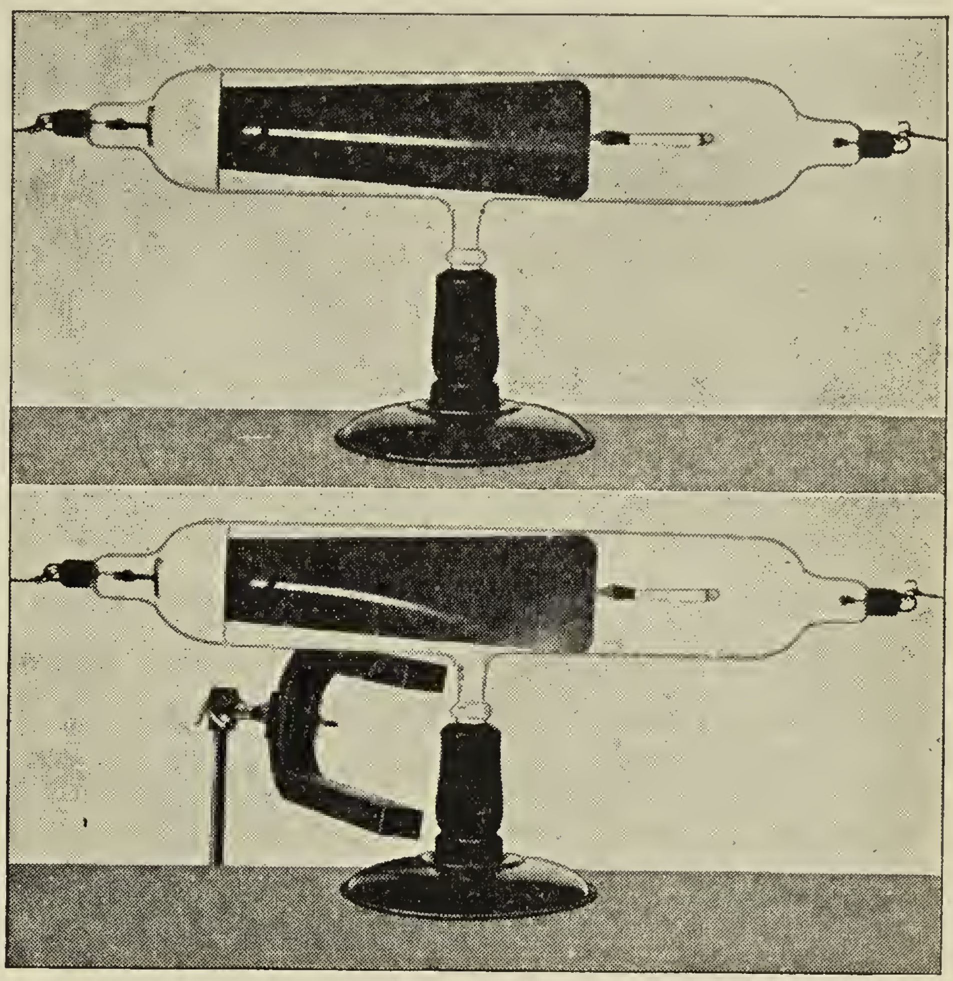
After the Greeks, the atomic idea seems to have slumbered for more than fifteen centuries. Then Newton in his thinking recognized atoms. He gives a clear-cut expression of his idea of the atom in the following passage:

> It seems probable to me that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles, of such sizes and figures, and with such properties, in such proportions to space, as most conduced to the end for which He formed them; and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces; no ordinary power being able to divide what God Himself made one in the first creation.

During all these centuries, however, man's opinion concerning the fundamental and indestructible nature of the atom was wholly erroneous, and this error continued to hold sway over the minds of scientists until the latter part of the nineteenth century. At that time a series of discoveries was initiated, one following the other in relatively quick succession, which completely upset the traditional view of the atom. In addition, it started a new method of attack—one whose achievements have paved the way for an entirely new conception of matter.

Investigation of the Nature of Matter Was Stimulated by the Phenomenon Displayed within the Crookes Tube. The first streaks of dawn appeared a long time before the full daylight of the new discoveries burst forth. In this achievement William Crookes may be said to have been the torchbearer. He became interested in the strange light phenomenon produced by an electric discharge in a vacuum. His work seems to have begun about 1878. By the use of an air pump he was able to make highly evacuated tubes. So nearly perfect was the vacuum in his tubes that the gas remaining in them was 20,000,000 times thinner than that of the atmosphere. Then when he threw this tube into action with an electric current, he got a most beautiful fluorescent display. Glowing, flickering streams of lighted particles shot from one electrode toward the other. The pole from which they were emitted had been called the *cathode*, from a Greek word which means "the way down." The pole to which they went had been designated the *anode*, meaning "the way up." Later these poles came to be recognized, respectively, as the negative and positive electrodes.

With these rays Crookes experimented, and in dark rooms he produced most beautiful displays. The young amateur was on the very threshold of a new discovery, but the electrical knowledge of that time did not enable him to interpret our now familiar electron effect. He believed the fluorescent stream to be a "fourth state" of matter which he had produced, as contrasted with gases, liquids, and solids. He experimented with these peculiar rays by placing a target in their path inside the tube. The target became heated. From this he wondered if these mysterious rays were capable of producing motion. Like a true scientist he tried it out. He devised a tiny double track inside the tube and placed on it a small paddle wheel, the ends of whose axle rested on the rails. He now directed the rays against the paddles. The wheel turned and quickly moved over the track to the other end of the tube. Here was unmistakable evidence that these manifestations within the tube were particles of some kind. Following up his investigation he found that the north pole of a magnet attracted the stream of particles toward the magnet, but the south pole deflected the particles away from the magnet. Here, then, was evidence that these rays were composed not only of particles but of *electrically charged* particles.



A Crookes tube

Note the attraction of the particles in the presence of the magnet

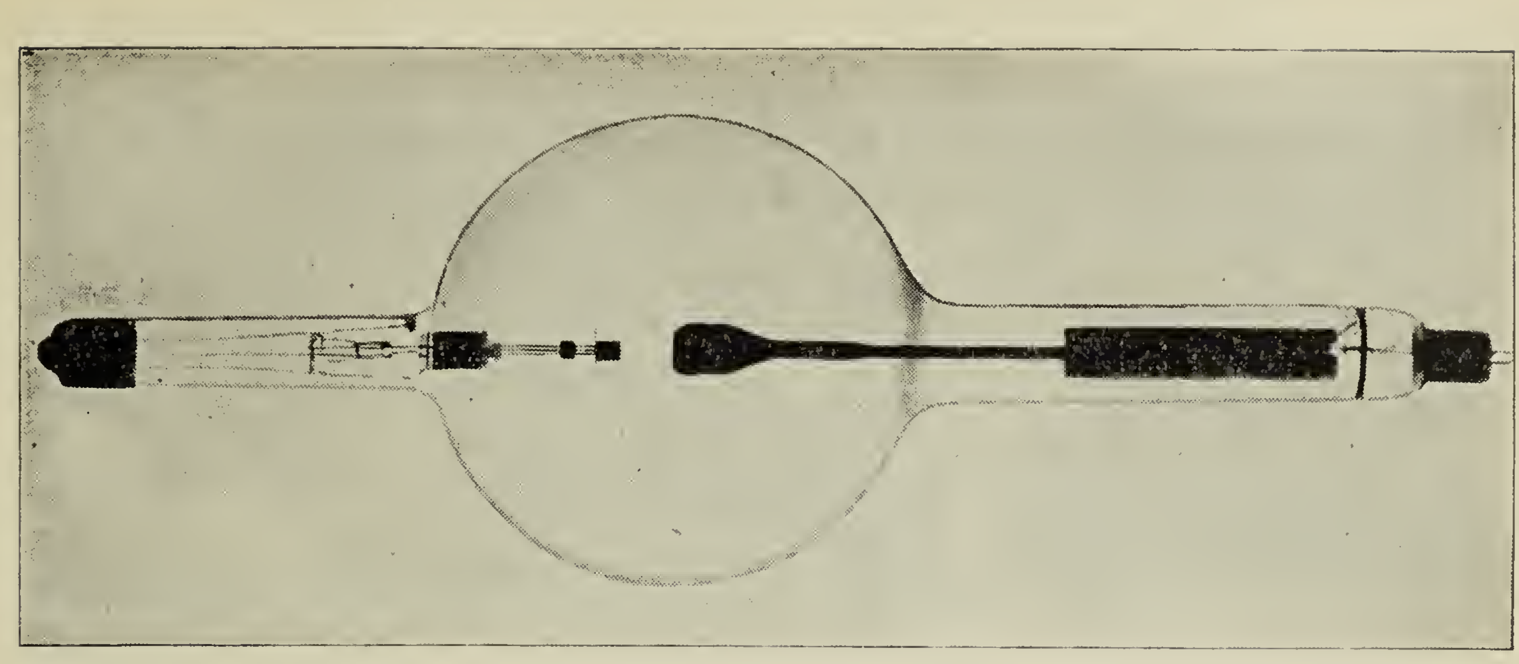
A modification of the tube with which Crookes worked was destined to play an important role in modern illumination and to form the basis of a great industry. The multicolored, flickering electric lights observed in almost every town and hamlet in the whole land today are but these special tubes in action. Their flashing signals or "darting arrows" tell us at night where to buy gasoline, find places of amusement, or locate a hotel. The varicolored, illuminated tubes used for this purpose are filled with some gas of reduced pressure, and an electric current is continuously or intermittently discharged through them. The pressure in the tube is reduced to approximately one that will support a column of mercury 1 cm high or less, and the color depends on the gas used. Helium gives a canary-yellow light; neon, a red one; and a combination of argon and mercury vapor, a blue-violet glow. Green, purple, and violet shades are also possible.

The years passed, and here and there, every once in a while, a new discovery was added to the growing store of knowledge. At length someone discovered that, regardless of the material—copper, aluminum, iron, or other metal—of which the cathode was made, the particles emitted from it were always the same. This was a momentous discovery. It has been said by one writer that no discovery in nineteenth-century physics was more interesting than this one. Here was evidence that all matter, regardless of its kind, had something in common in its composition, and that an electric current could expel this common portion.

Sir Joseph J. Thomson, in 1897, attempted to find out how heavy the rays manifested in the Crookes tube were, or, in more exact terms, what their mass was. Up to that time the hydrogen atom was believed to be the smallest and the lightest particle in the material universe. Thomson determined that the mass of one of these negatively charged particles was about $\frac{1}{1800}$ that of the hydrogen atom—a remarkably close approximation for the crude method of procedure then available. By the application of refined techniques, the mass of the particle was later determined to be about $\frac{1}{1845}$ as great as that of the hydrogen atom. Still the question as to the composition of the atom remained. How much of it consisted of these negatively charged particles, and how much of something else was not yet known.

Röntgen Discovers X Rays. To continue our story we must go to the laboratory of a German physicist, Professor Röntgen, at Würzburg. He was prying about to see what he could find out regarding these strange rays manifested in the Crookes tube. On one occasion he threw an opaque cover over a tube with which he was working and turned the electric switch. A sensitive screen coated with barium and platinum compounds stood on a table near by. This screen suddenly began to glow with a fluorescent display. Having the eye of a trained scientist, Röntgen's interest was thoroughly aroused. He repeated the incident with identical results. Here seemed to be a brand-new kind of radiation, one that could pass right through opaque substances and affect sensitized plates some distance away.

Another striking discovery is reported. As the story goes, Röntgen and his assistant were bothered with the fogging of their photographic plates that were in the room while these experiments were in progress. The plates were kept tightly wrapped in their accustomed packages; yet the defect persisted. As they were developing one of the fogged plates, the assistant noted the image of a bunch of keys which by chance had been lying on the top of the box



A Coolidge X-ray tube

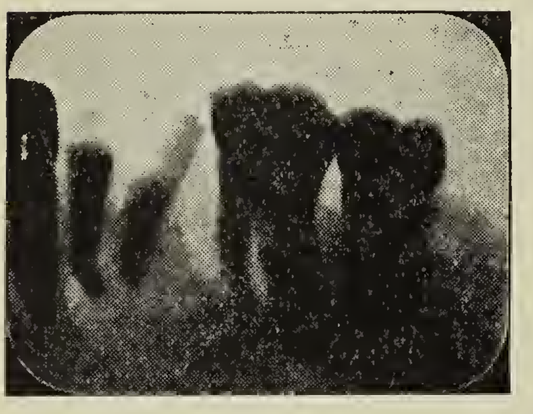
Note the target, right center

in which the plate had been kept while Röntgen was experimenting. Röntgen immediately looked into this. He discovered that the fogging was due to the strange rays with which he had been working, and that the interruption of these rays by the keys had produced the image of the keys on the plate.

Now the taking of pictures in this strange way became the dominant aim of Röntgen and his assistant. The rays were found to pass, apparently unobstructed, not only through dark cloth but through wood, flesh, or even stone and at the same time could be made to take a picture of denser embedded objects.

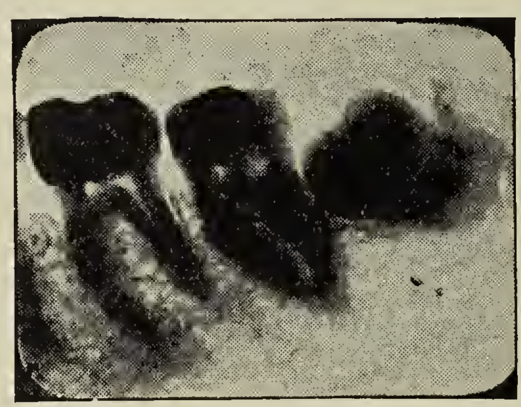
It was to an astonished group assembled at a Christmas Eve meeting of the German Physical Society at Berlin in 1895 that Professor Röntgen showed his first X-ray pictures. He exhibited photographs of the bones of his hand, and of coins and keys taken through the opaque walls of his leather purse. The spectators were amazed. These were indeed mysterious rays; for they defied opaque screens and took pictures of objects completely hidden from sight. No one knew the nature of these baffling rays, not even Röntgen himself. Consequently they were called X rays after the unknown quantity in algebraic equations.

The real nature of these rays remained a mystery for some time. Investigation showed that Röntgen had placed a metal target in the path of a stream of cathode rays, and from the activated face of this target the new rays, or X rays, had emanated. Further examination revealed that whenever almost any surface, but preferably a metal one, was bombarded with these negatively charged cathode particles, the result was the production of these penetrating X rays.



X ray of teeth

Showing destruction of dental ridge (bony section between the teeth) by pyorrhea

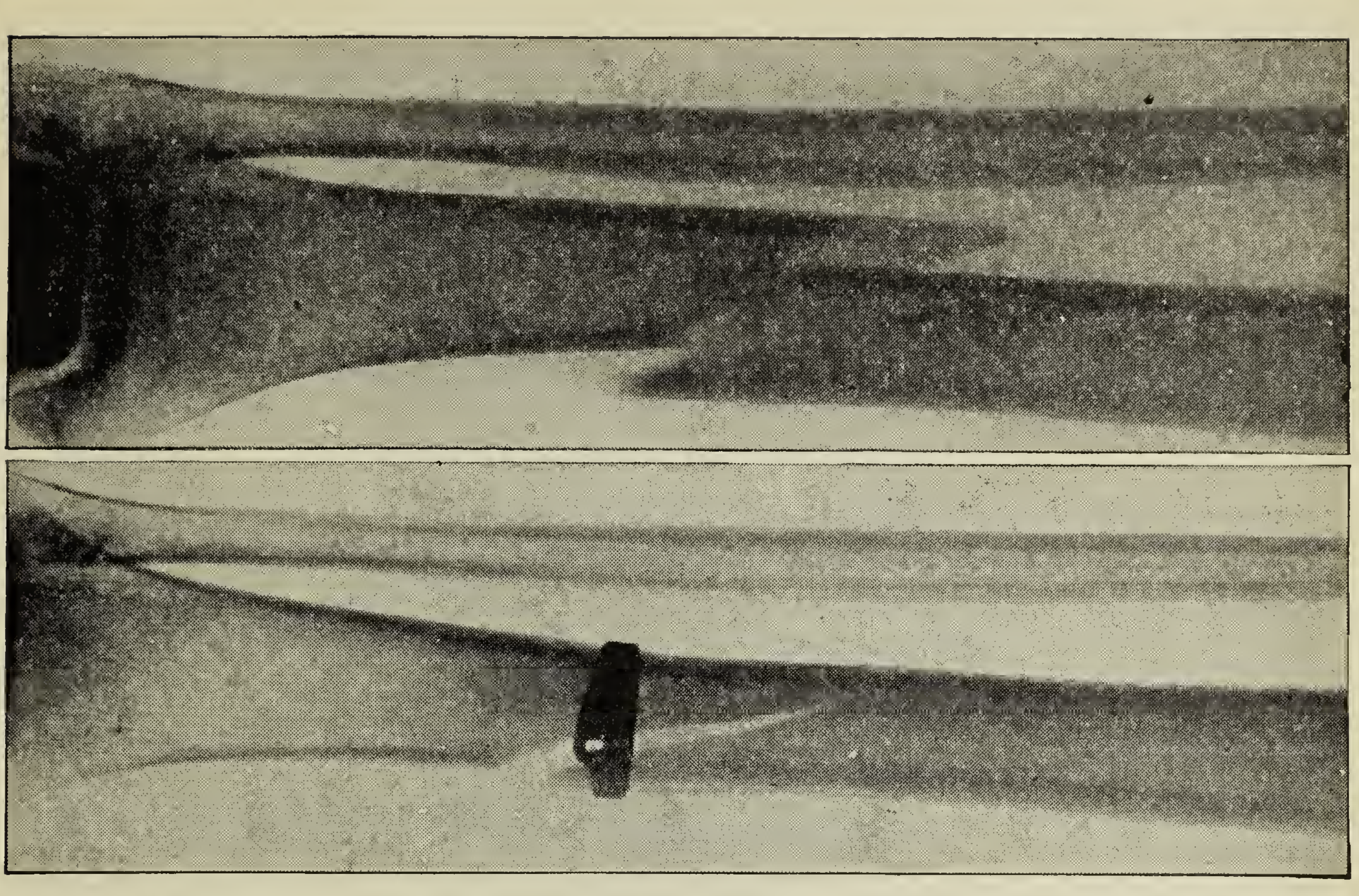


X ray of teeth

Showing impacted wisdom tooth

The importance of these rays in surgery was recognized almost immediately. They were rapidly adopted as a diagnostic and surgical aid. Pictures of the alimentary canal during the progress of a barium meal reveal the presence of ulcers, strictures, adhesions, and other pathological conditions. Dentists employ X rays to locate ulcers and pus pockets at the roots of teeth. These infections act as focal points from which tissue-destroying microorganisms may be carried to vital organs of the body. Bone fractures are seldom reduced without the aid of X rays. Formerly surgeons had to judge the accuracy of a reduced bone fracture largely by the sense of touch, but the results of this method were often unsatisfactory when the affected bone was deeply embedded in the flesh. Now the use of X rays practically removes uncertainty from this branch of surgery. During the first World War thousands of X-ray pictures were taken of injured soldiers to locate bullets and pieces of embedded shrapnel.

Recently, as one writer has expressed it, X rays "have gone into business." They are now being employed in packing plants, foundries, and automobile service stations. They are used to determine the inner condition of telephone poles and to detect frosted citrus fruit. A California packing company, after a damaging frost, salvaged 2,000,000 boxes of oranges that would have been condemned under ordinary methods. The value of the fruit thus saved was $7,500,000. Makers of chewing gum, candy, and tobacco products also employ these rays for the purpose of eliminating foreign substances. They are likewise being used to locate nails and bits of glass in automobile tires. One large company found such objects in 99 per cent of the tires on one hundred cars selected at random. It is probable that in the future many service stations will be fitted with X rays for inspecting the tires of their patrons. Approximately five thousand shoe stores use X rays in fitting footwear. They are being employed extensively to find defects in iron and steel products. In this way flaws such as bubbles and cracks can be detected. Eighty miles of welded seams for the steel penstock linings for Boulder Dam were X-rayed for this purpose. A



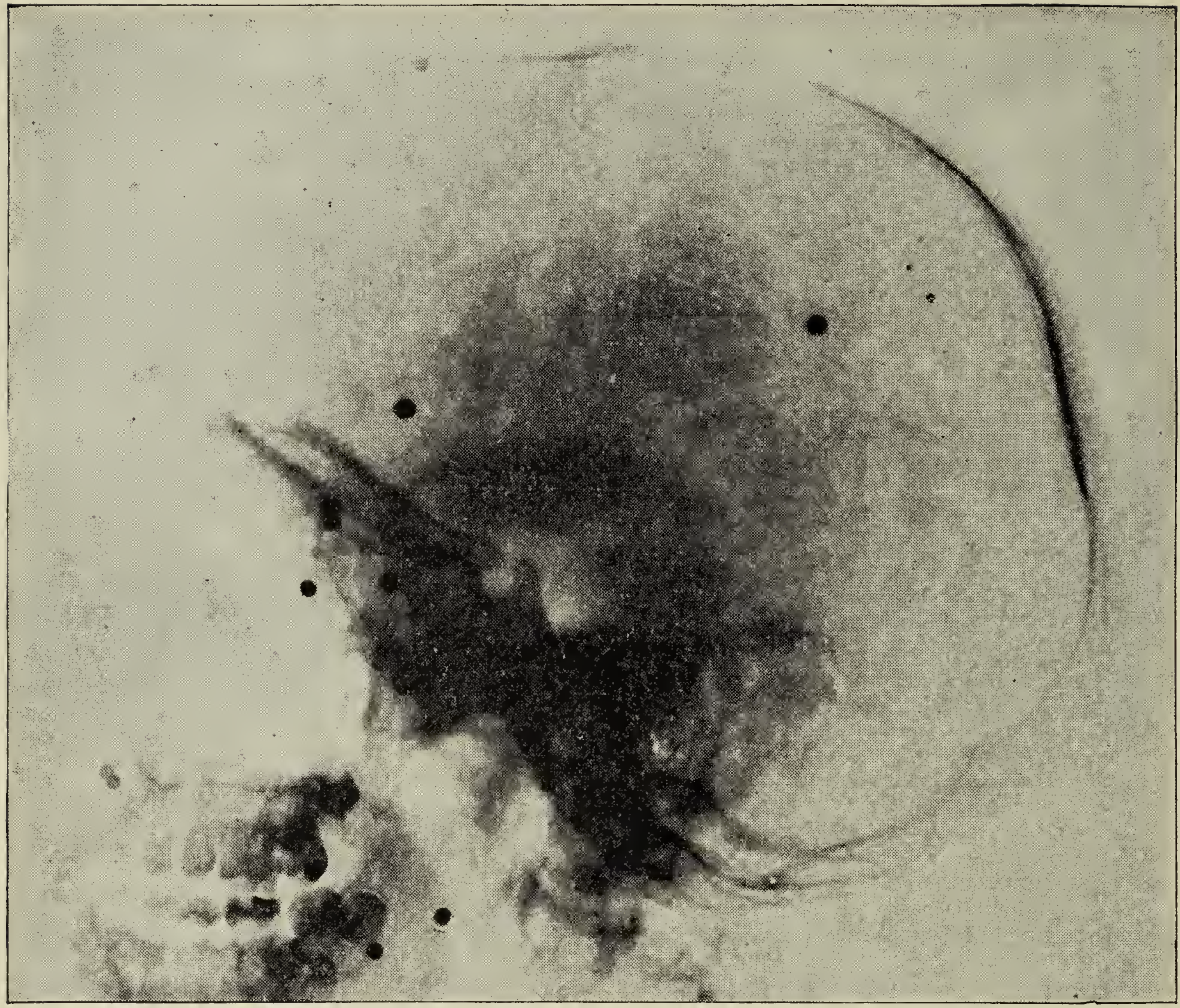
Above, X ray, showing bone fracture before reduction; below, X ray of same fracture after reduction

Note the silver band that holds the bone in place

navy inspector by X-raying a turbine for one of the naval destroyers discovered a crack in the casting, which had been filled with a metal plug and plated over by the contractor to conceal it. In New York City X-ray examination of a natural-pearl necklace valued at twenty thousand dollars revealed four culture pearls scarcely worth a dollar each.

Becquerel Discovers that Uranium Salts Are Radioactive. In the University of Paris, Henri Becquerel, a physicist, had become interested in X rays. Certain substances exhibit the quality of phosphorescence; that is, after they have been subjected to the action of sunlight for some time, they glow. Becquerel had discovered that salts of uranium could be made phosphorescent and was interested in finding out whether these luminous substances emitted X rays, too.

The story has come to us that one day, in connection with his research, he unthinkingly laid a piece of uranium ore in the drawer of his laboratory desk directly over a wrapped sensitized photographic plate which had been exposed but not developed. He shut the drawer and turned his attention to other experiments on phosphorescence. Two weeks passed by, and he again was rummaging in the drawer when he noticed the plate. Pushing the ore aside, he took up the plate and passed it over to an assistant to be developed. The next morn-



X ray of head, showing shot embedded in the flesh

ing the assistant was apologetic. He declared that the plate had been developed carefully but for some reason showed a great dark-colored blotch. Had Becquerel been less observing, he might have reprimanded his assistant and missed a great discovery. But he noted that the huge blotch was in the center of the plate, while the margin all the way round was free from this defect. His experience in the past had shown that, owing to a leak in the camera or careless handling, plates sometimes get light-struck from the side, but in the center alone—never. The ore, without first being illuminated, had emitted rays that caused the blotch on the plate.

Immediately his logical mind went from effect to cause. The uranium ore must, in some unexplained way, have produced the blotch. He now purposely repeated what had happened, with the same results. At first he was tempted to believe that the uranium ore was the sole cause of the rays. But he performed the experiment several times, using other kinds of ore. He found that a pitchblende from Bohemia was especially potent. In fact, it registered an output of energy on the sensitized plate out of all proportion to the percentage of uranium in the ore. There must have been some other more active principle present. Being a busy scientist and knowing that the search for this hidden element would doubtless prove to be an arduous and time-consuming one, he requested the Curies to undertake the task.

The Curies Discover Radium. Inspired by the new discoveries that were being made in physics and especially by the strange experience of Becquerel with his ores, Professor Curie and his Polish wife, Marie, eagerly consented to make the search. Their laboratory was inadequately equipped for this difficult task. Finally, after the prodigious labor of working over eight tons of ore, they secured about half a teaspoonful of a highly radioactive compound. It proved to be about a million times as active as uranium itself. For the remarkable substance that was active in this compound there could be but one appropriate name—*radium.*

Radium proved to possess a "fascinating array" of properties. Like X rays it ionized air into electrified particles; it excited phosphorescence; it quickly darkened photographic plates; it liberated great quantities of heat; it produced chemical changes; and it was found to kill microorganisms readily. Within an hour's time it liberated enough heat to raise an equal weight of water from the freezing point to the boiling point.

Research Revealed the Nature of Radium Emanations. Professors Ernest Rutherford and Frederick Soddy, two English scientists working at McGill University, decided to attack the problem of finding out what these strange emanations were. They soon found that radioactive substances were literally shooting themselves away. These substances were disintegrating, and in so doing were liberating great quantities of subatomic energy, which manifested itself as flashes of light, heat, and all the other effects that radioactive substances exhibit.

These men, as well as Sir William Ramsay, found that when radium disintegrates, three types of emanations are given off. They were named (after certain letters in the Greek alphabet) the alpha and beta particles and the gamma rays. The alpha particles, found to be four times the mass of the hydrogen atom, carry a positive electric charge. They are, relatively speaking, massive particles and are sent out like bullets from a rifle. They travel about 12,000 miles per second and have been said to be "the most powerful missiles known to science."

The beta particles, being much less massive, were found to be hurled out with terrific speed, which ranged from 60,000 to approximately 180,000 miles per second. Because of this high speed, their penetrating power, like that of a

Bureau of Mines, Ottawa, Canada

Photograph of pitchblende taken by its own light

fast bullet, was very great. These particles proved to be identical with the cathode rays produced by Crookes in his tube. Moreover, they were found to be nothing more nor less than negative charges of electricity; later these were named *electrons.*

These negatively charged particles were destined for great performances in the drama of modern life. Although electric currents had been developed previously, no one knew anything about their nature. Men knew only how they behaved and some of the things that they could be made to do. These electrons, when moving in a stream, subsequently became identified as the electric current. In this capacity they have become the chief actors in an industry whose capital outlay runs into billions of dollars. When moving as an electric current toward a positive pole, they become the chief agent in illuminating the civilized world at night, in turning the wheels of industry, and in making possible practically all the conveniences of the modern household. Our lives are directly affected by them from the time we turn the electric-light switch, on a winter's morning, to the moment we turn off the radio and retire. No other discovery has more profoundly affected the course of present-day experience.

The new discoveries as to the nature of radium emanations were most revolutionary in their import; for previous to this, from time immemorial, two indestructible entities had been recognized. They were matter and energy. Now the line of demarcation between the two seemed to be fading.

Rutherford examined some of the alpha particles with the spectroscope. To his astonishment, their spectrum showed the distinct bright lines of the element helium. Here was more disconcerting evidence. For physical scientists had taught with finality that elements are immutable—that one cannot be changed into another. But now not only was radium disintegrating, but it was also producing a second element, helium, and accompanying the transformation with broadsides of negatively charged electrons. Later these alpha particles were found to be identical with the helium atom when its two outer electrons are stripped off. If they are permitted to stream for months and months into a small sealed and evacuated glass tube, a strange and unexpected result occurs. For these stripped atoms pick up two electrons from the multitudes available everywhere in the world and become just ordinary, everyday inert helium atoms.

The gamma emanations produced were not particulate in nature, and consequently carried no electric charge. On the contrary, they were found to be a sort of X ray similar to the X rays discovered by Röntgen. They traveled at the velocity of light.

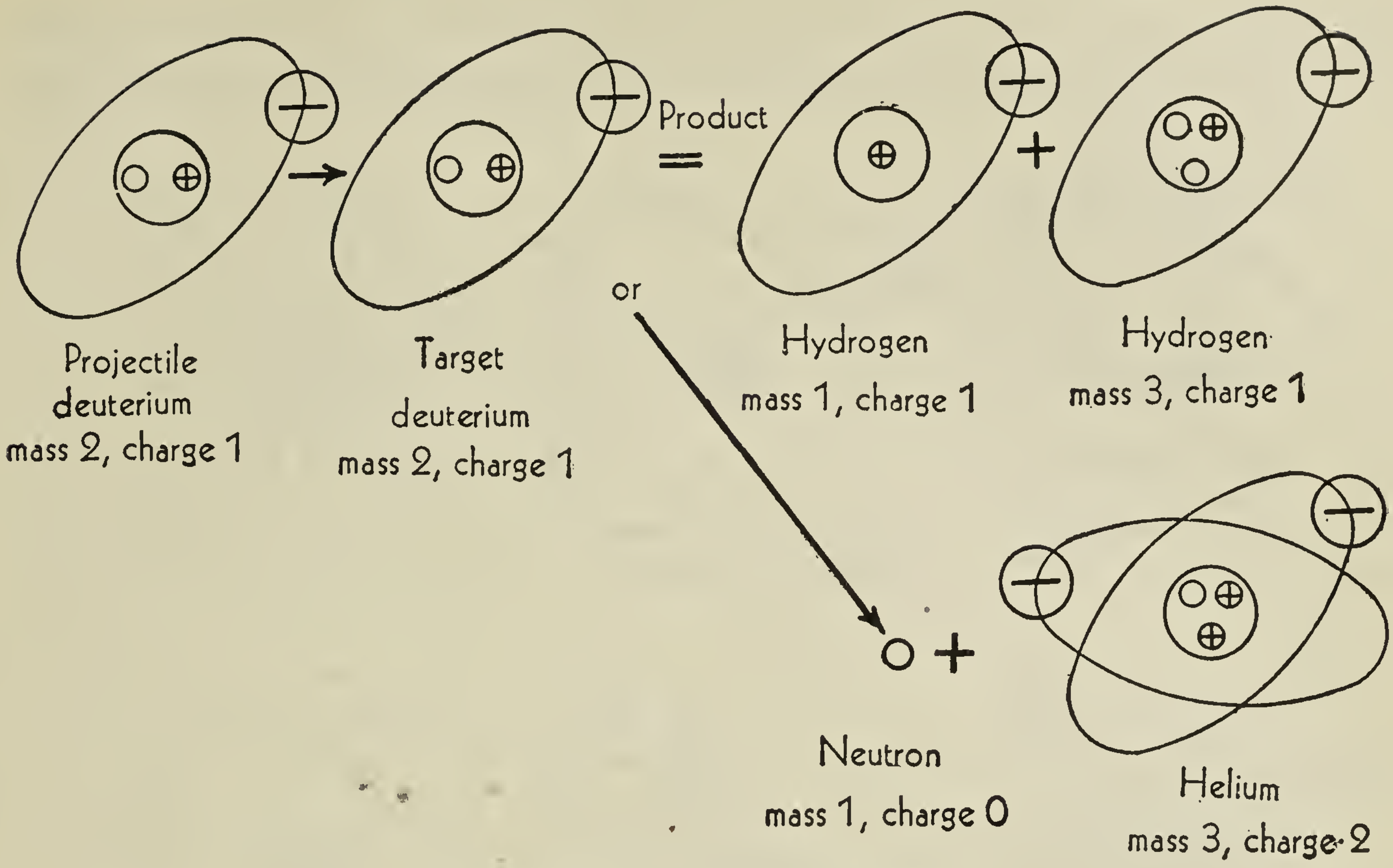
Radium Is Derived from a More Complex Substance. Physicists, after witnessing the disintegrating performance of radium, began to wonder whether radium itself might not in turn be the offspring of some other more complex element and result from a similar stepping-down process of radioactive emanations. Vigorous inquiry was pressed, and it was followed quickly by its reward. Most certainly radium had a parent, and that ancestor was none other than uranium, whose salts Becquerel had used in his classic discovery. Moreover, it was found not only that uranium disintegrated to form radium, but that a whole series of elemental transformations followed in the train of this initial change, resulting in lead as a final product. At some of the steps stripped helium atoms, as alpha particles, were liberated as a by-product. The time involved in this long series of changes, as gradually worked out by the investigators, was astounding. The uranium-radium change, for instance, involves the most time. It is estimated that it would take uranium 4,670,000,000 years to disintegrate one half of its mass into radium. Since the number of atoms which explode to produce this transformation depends upon the total number originally present, the amount of decomposition constantly falls as the quantity of uranium diminishes. Radium loses half of its mass in 1690 years and half the remaining mass during the next 1690 years, and the disintegration continues at this rate. Some of the transformations are very

Disintegration of Uranium I to Lead. When shift is to a group to the left, an alpha particle has been lost; when to the right, a beta particle

Group	0	I	II	III	IV	V	VI	VII
Element Atomic Wt. Half Period					Lead 206 Not radio-active	α		
Element Atomic Wt. Half Period					Radium D β 210 22 years	Radium E β 210 α 4.9 days	Polonium 210 140 days	
Element Atomic Wt. Half Period					Radium B β 214 26.8 min.	Radium C β 214 α	Radium C′ 214 10^{-6} sec.	
Element Atomic Wt. Half Period							*Radium A 218 3.05 min.	α
Element Atomic Wt. Half Period	*Radon 222 3.82 days	α						
Element Atomic Wt. Half Period			Radium 226 1,690 years	α				
Element Atomic Wt. Half Period					Ionium 230 8×10^4 years	α		
Element Atomic Wt. Half Period					Uranium X_1 β 234 24.5 days	Uranium X_2 234	β Uranium II 234 3×10^5 years	
Element Atomic Wt. Half Period						α	Uranium I 238 4.4×10^9 years	

*Back to group VI

α loss of Alpha Particle
β loss of Beta Particle


Projectile
deuterium
mass 2, charge 1
Target
deuterium
mass 2, charge 1
Product
=
+
Hydrogen
mass 1, charge 1
Hydrogen
mass 3, charge 1
or
Neutron
mass 1, charge 0
Helium
mass 3, charge 2

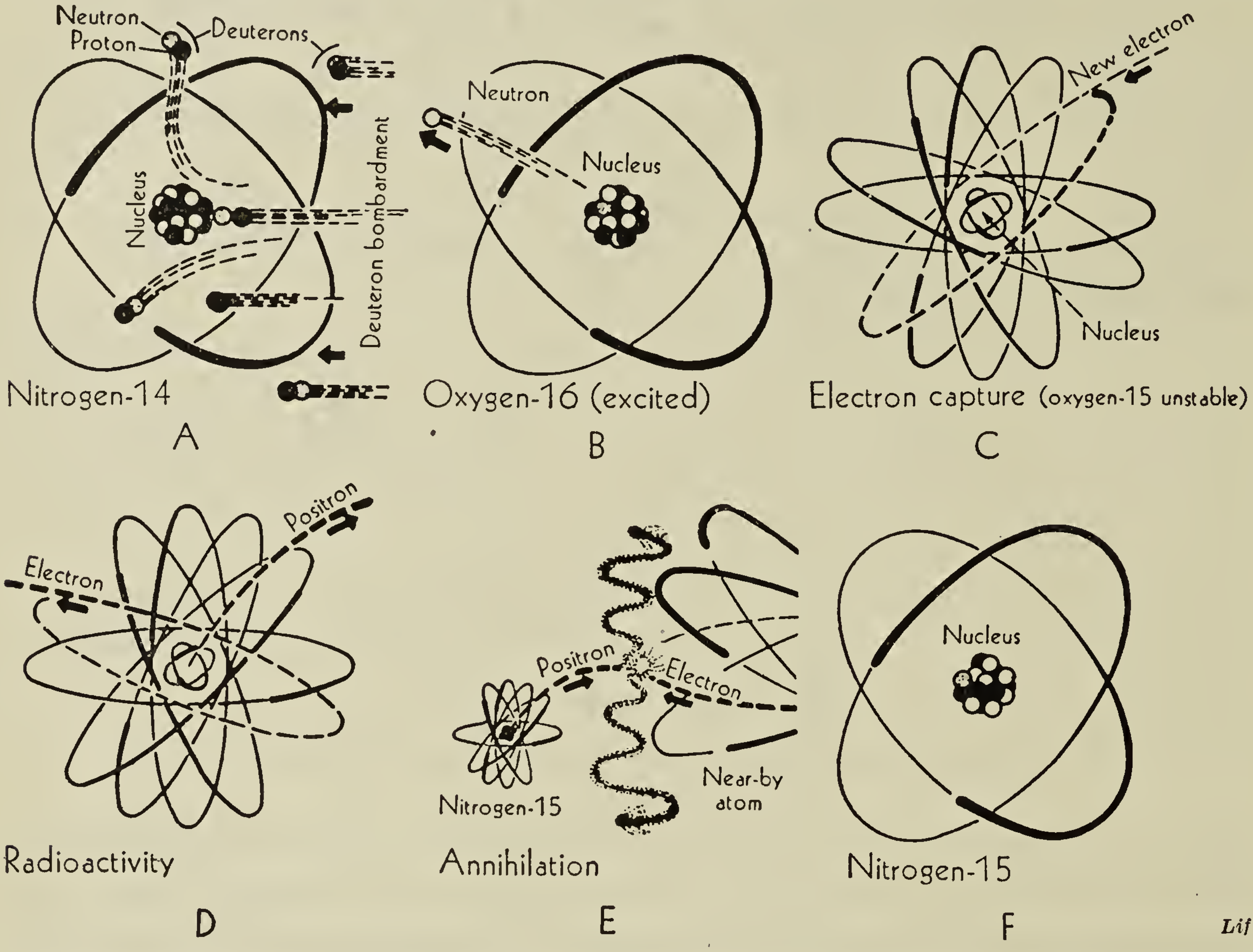
Atoms may be made radioactive

When deuterium is bombarded with deuterium, two types of reaction may occur

rapid and involve but a few minutes, or seconds even. Yet the same sequence is followed throughout the whole series of changes: one half the present mass in a definite duration of time and one half the remaining amount in an equal period. Why this should be true is a baffling puzzle. Just why of two atoms of uranium existing side by side and theoretically alike in every respect one should explode the next instant and the other wait a billion years is at present inexplicable.

Other Elements Can Be Decomposed into Simpler Ones. Investigation revealed that several elements, such as uranium, thorium, radium, and actinium, disintegrate naturally without being stimulated. Through this action simpler elements are produced in the process, and frequently a stream of electrons is expelled besides. With this fact before them, inquisitive workers began to wonder whether all more complex elements might not be decomposed to form simpler ones — indeed, whether all other substances might not be reduced to the simplest element, hydrogen, just as Prout, the English chemist, had philosophically set forth a hundred years before. With this question before them, Rutherford and a co-worker named Chadwick set to work.

By a cleverly devised method, they bombarded atoms of nitrogen gas with high-speed alpha particles from radium, hurled at a velocity of 12,000 miles per second. These projectiles, whenever a hit was scored, tore the atoms of nitrogen to pieces, and what a significant revelation their shattered form presented! When the nitrogen atom was disrupted, it yielded hydrogen and a residue of carbon atoms. The great question in this case had been answered. Elements not radioactive can be torn down into simpler ones with hydrogen atoms as a by-product. The alchemists of the Middle Ages had failed in their attempt to transmute elements, but the "modern alchemists" Rutherford and Chadwick had succeeded.


Neutron
Proton
Deuterons
Nucleus
Deuteron bombardment
Nitrogen-14
A
Neutron
Nucleus
Oxygen-16 (excited)
B
New electron
Nucleus
Electron capture (oxygen-15 unstable)
C
Positron
Electron
Radioactivity
D
Positron
Electron
Nitrogen-15
Near-by atom
Annihilation
E
Nucleus
Nitrogen-15
F

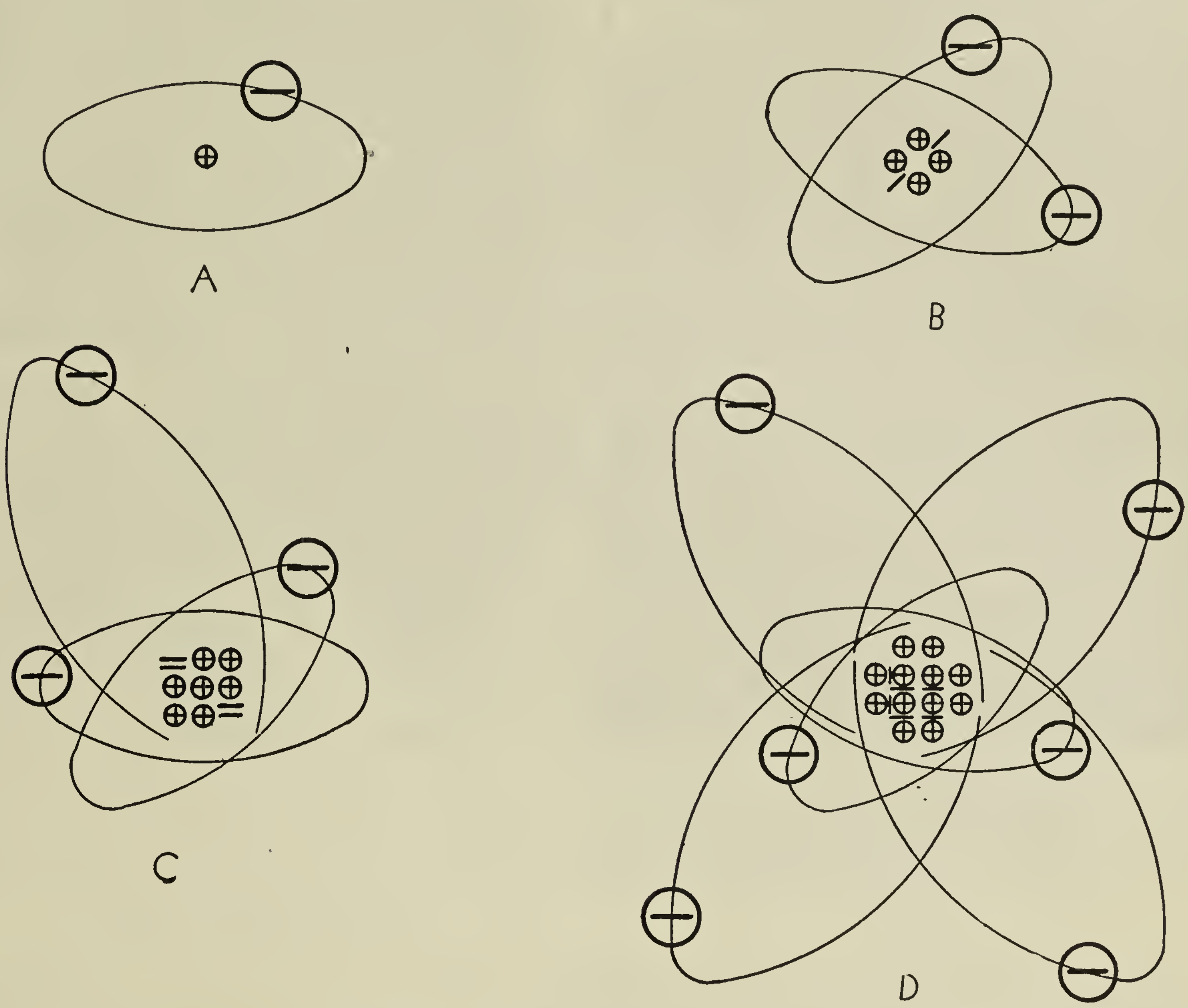
Life

Transmutation of the nitrogen atom as the result of bombardment with deuterons

The outer electron orbits have been omitted from A, B, and F.

Other elements were attacked with identically similar results. Aluminum was made to yield hydrogen and magnesium; phosphorus yielded hydrogen and silicon; sodium gave hydrogen and neon. Here complex elements were being resolved into simpler ones as readily as a glacier melts into water. It seems too bad that the spirit of Prout could not have been looking on that day to see his prophetic theory verified.

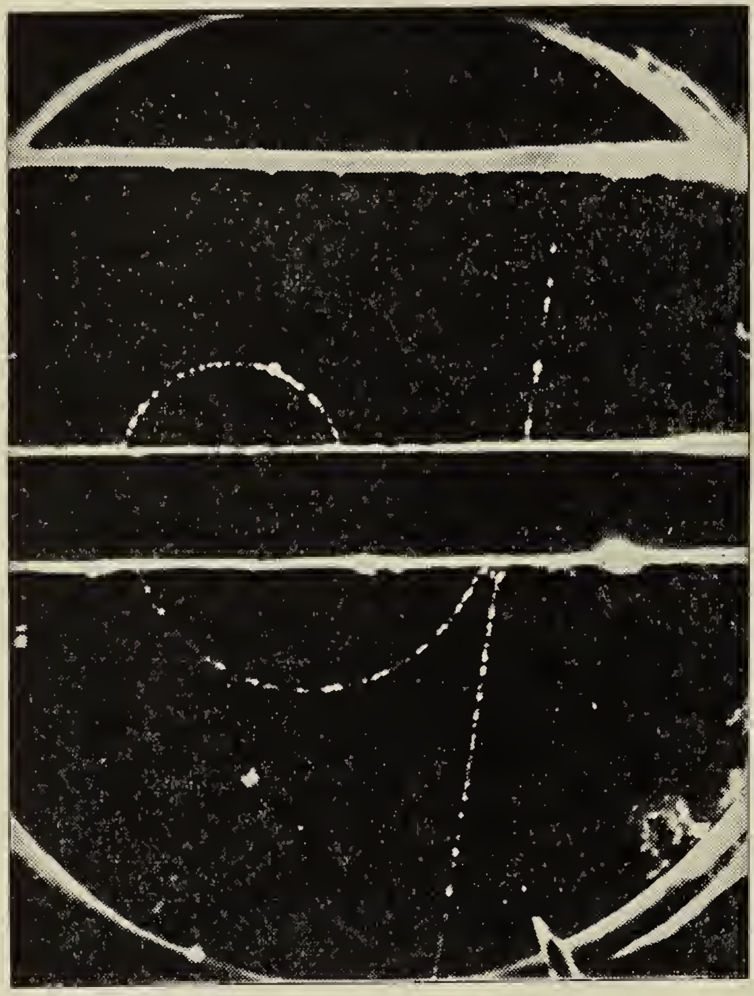
Our Concept of the Relation of Matter and Energy Has Changed. Thus, one after another, these revolutionary discoveries followed in quick succession. The final result was an entirely new view of the composition and structure of matter. The electron of the atom had been found to be nothing more than a negative charge of electricity, and the nucleus was chiefly one or more positive charges. The beliefs held by physicists for over two thousand years had been exploded. According to modern theory, matter and energy are not distinct entities but different expressions of the same thing—electrical energy. So, in the last analysis, when we wish to think about a chair, our bodies, or a star, we are forced to look upon them as being, in a sense, identical; they are but expressions of different kinds of electrical organization.



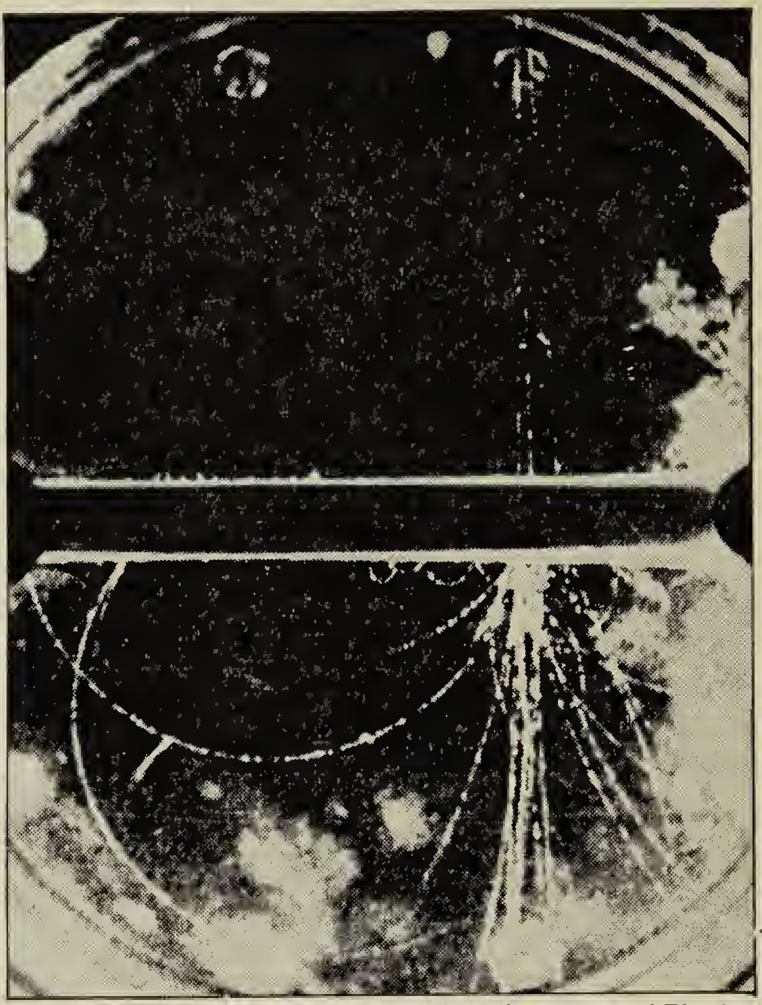
Bohr's original theory of the atom

A, hydrogen, 1 proton (+) in the nucleus, 1 electron (—) in the K shell. *B*, helium, 4 protons, 2 electrons in the nucleus, 2 electrons in the K shell. *C*, lithium, 7 protons, 4 electrons in the nucleus, 3 electrons in the outer energy shells. *D*, carbon, 12 protons, 6 electrons in the nucleus, 6 electrons in outer shells

The Atom Is Believed to Be Complex. The new physics had not destroyed the atom in any sense. On the contrary, its reality had been firmly established. Nevertheless it now bore an entirely different structure from that which had previously been assumed. Instead of being a hard, smooth, indivisible particle, as Newton had postulated, it seemed to be a system of balanced electric charges.



High-speed cosmic-ray particle pierces a piece of carbon ½-inch thick, dislodging an electron in the carbon. The electron takes a curved path



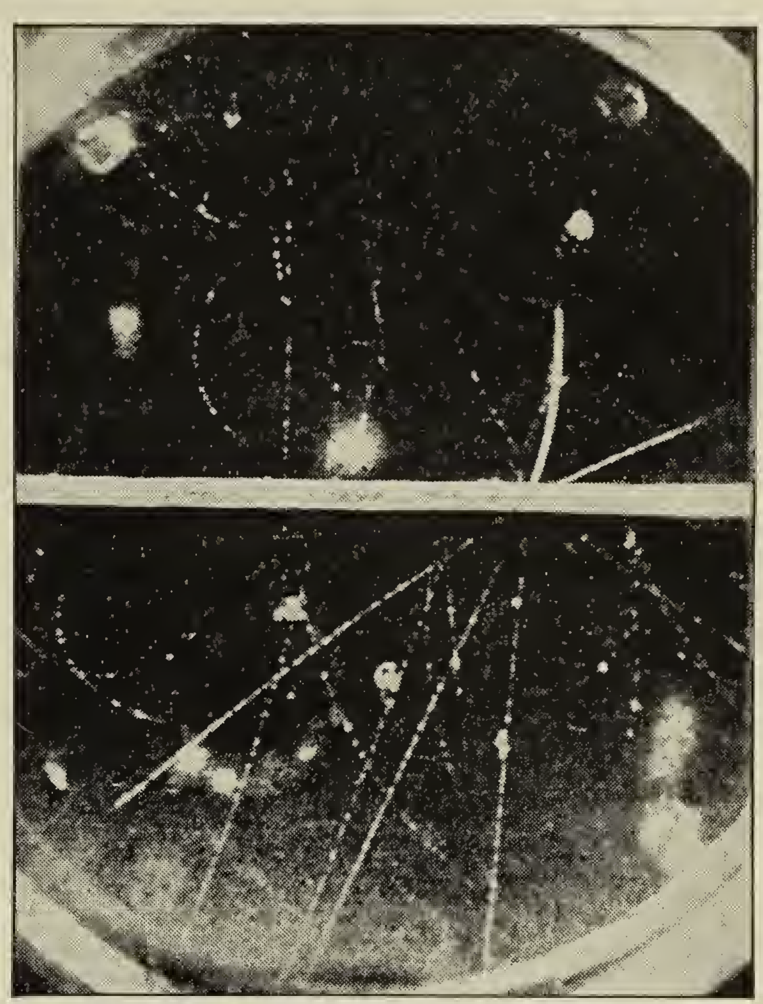
Carl D. Anderson, Norman Bridge Laboratory of Physics

Three high-energy cosmic-ray particles strike the upper surface of a ½-inch platinum plate, giving rise to a "shower" of positive and negative electrons below the plate

Take the hydrogen atom, for example, which is the simplest and lightest atom known. It was found to be composed of a single positive charge, called a proton, with one electron associated with it. Most of the mass resides in the proton. In fact, the proton is about 1845 times as heavy as the electron.

The helium atom is the next lightest, but its weight is four times that of hydrogen. Hence its nucleus, it would seem, must consist of four protons. But with respect to this concept a formidable difficulty arose. If the nucleus were composed of four protons, one would expect to find it carrying four positive charges and hence, in its electrically balanced state, four electrons outside the nucleus. But investigation showed that in its balanced, neutral state, the helium nucleus carries only two positive charges with two outer electrons to balance them. This discrepancy was not cleared up until another particle was discovered.

This achievement was reserved for the brilliant English physicist Chadwick, in 1932. The Kelly Hospital in Baltimore gave him a number of old radium-emanation tubes which had lost their activity to the point where they were of little value for medical purposes, but which did contain some radioactive residues. From these tubes Chadwick extracted some polonium, which the reader will remember (see page 148) as one of the radioactive decomposition products of radium. This polonium was spread over a small plate which was placed about an inch away from another plate of the element beryllium. In this way the beryllium was subjected to bombardment by the fast alpha particles hurled out spontaneously from the polonium. Chadwick found, when the beryllium was thus excited, that it in turn emitted a particle of tremendous penetrating power. Further investigation revealed that this new particle smashed the atoms of air through which it crashed, ionizing them and disrupting any atomic nuclei which it happened to hit. Strangest of all, this particle was electrically neutral, and from this condition came the name *neutron*.



Carl D. Anderson, Norman Bridge Laboratory of Physics

An atom of lead is disrupted by cosmic rays

The six tracks in the lower half of the picture arising from a point in the plate are due to the products of disintegration

The discovery of the neutron was epoch-making in that it solved many of the problems attending the physicists' previous conception of the atom. To be specific, the helium nucleus now became two neutrons and two protons, with each of the latter carrying its positive charge. These nuclear charges are balanced by the negative charges of the electrons outside the nucleus. Lithium, the third element in the atomic series (see page 164), has three electrons in the atom. Consequently it is believed to have a nucleus composed of three protons and four neutrons. With still heavier elements, the number of both protons and neutrons in the nucleus increases.

During the time that Chadwick was ferreting out the neutron, Anderson and Millikan were busily working with cosmic rays at the California Institute of Technology. Cosmic rays are very short, penetrating rays which apparently come from outer space.[1] Because they are so short and piercing, they are said to be the hardest rays known to science. This character enables them to pass right through water, stones, and metal plates of surprising thickness. It is inescapable that our bodies are penetrated by them constantly.

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[1] It now seems that many of these hard rays are not the cosmic rays themselves, but are emanations from gaseous molecules of the atmosphere which have been disrupted by the incoming cosmic rays.

Anderson and Millikan permitted cosmic rays to shoot through a Wilson cloud chamber, which is a device used to make the path of electrons and other emanating particles visible by forming in their wake a trail of minute condensed water particles. These rays collided with atoms and knocked electrons from them. The electrons freed by these disruptive rays were hurled out from their respective atoms with tremendous velocity. Some of them emerged with a speed of over 180,000 miles a second. Under the influence of the magnetic field they all tended to bend toward the same side of the cloud chamber. Thus, as Anderson says, the paths of these particles were seen much as the wake of a ship may be seen by an observer in an airplane flying very high, though the ship itself may not be visible.

To the surprise of the investigators, however, every once in a while a particle emerged whose path bent in the direction directly opposite to that of the emerging electrons. Moreover, the curvature of its path showed that its mass was just about equal to that of the electron. For particles that behaved in this strange way, there was but one conclusion: that was that positively charged particles, comparable in mass to the electron, can be expelled from atomic nuclei as they are disrupted. Thus were positive electrons, or *positrons*, discovered.

The exact relation between electrons, protons, neutrons, and positrons is not at present known. Anderson says, "It appears quite plausible that under certain conditions a negative electron and a proton may be formed out of a neutron; and similarly a positron and a neutron may be formed out of a proton."[1] Rutherford likewise stated before his death that "the expulsion of a negative electron from the nucleus may be connected with the change of a neutron into a proton, while the escape of a positive electron (positron) may be connected with the reverse operation."[2] Doubtless in time the causal relationship existing among all these particles will be made clear.

The positron in nature is believed to be an extremely transitory particle. Owing to electrical attraction, it quickly collides with an oppositely charged electron and is destroyed. When it passes through water or air, this is believed to take place within a millionth of a second or less. Strange to say, also, where this collision occurs, a most unusual thing is believed to happen. For both the positron and the electron are thought to be annihilated, and a pair of light waves, or radiant energy emanations, appear in their place. Here we have new evidence that matter is but a special form of energy.

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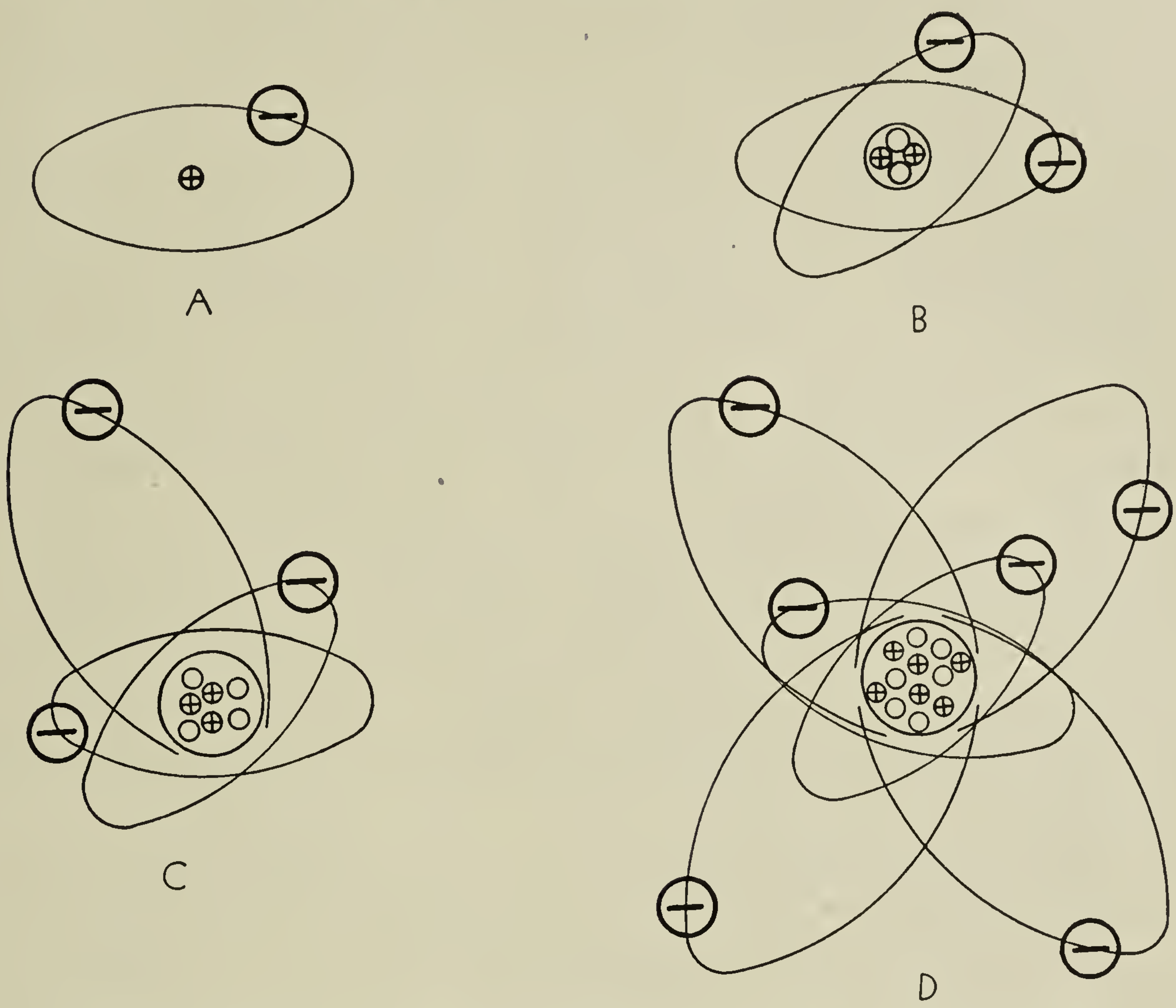
[1] *Annual Report, Smithsonian Institution, 1935*, p. 242.

[2] *Annual Report, Smithsonian Institution, 1936*, p. 174.



Bohr's concept of the atom as modified by the discovery of the neutron

A, hydrogen; *B*, helium; *C*, lithium; *D*, carbon

A new particle, the mesotron, has been recently reported. Its mass has been given by different investigators as ranging all the way from 130 to 700 times that of the electron. Mesotrons are found in the atmosphere, and are very hard in the sense that they are extremely penetrating. Some of them are capable of passing through several feet of lead or even several hundred feet of less dense material, such as rock. They are apparently very short-lived, disintegrating in about one-millionth of a second, presumably into an electron and a theoretical particle called a neutrino, which has not yet been discovered. According to Anderson, "the manner in which they are produced is completely obscure."

The Exact Structure of the Atom Is Difficult to Determine. Although the composition of the atom has been fairly well established on a tentative basis, the structural relation of its component parts has proved to be more baffling. Indeed, precisely how the electrons outside the nucleus are arranged is not known. Several theories have been proposed; but with these minute entities, far below visibility with the highest power of the microscope, it is not surprising that physicists sometimes proceed with faltering step. Indeed, what is surprising is that they have been able to make so many illuminating discoveries.

Perhaps the best picture of the atom, for our purpose, is that proposed by Niels Bohr, a Danish physicist and Nobel-prize winner. Previously it had been fairly well established that the compact nucleus occupies a position near the center of the atom. Bohr, like Rutherford, conceived the electrons to be circulating about this central nucleus in definite orbital paths, but with this modification: the electrons might jump from one orbit to another. They might jump either inward toward the center of the atom or outward from it according as energy was lost from or applied to the atom.

Bohr's modified atom was a distinct step forward in atomic science. It illuminated the whole field of chemical reactions, as we shall see later, and threw much light on the source of related physical phenomena. But this theory in turn encountered its difficulties and is likely to be modified in view of other discoveries that are being made, but which are too difficult to attempt to explain here.

The Atom Contains Much Space. We cannot profitably close this chapter in which we have traced man's evolving conception of the atom without noting the spatial characteristics of the atom. When we are talking about electrons, protons, and neutrons, we are dealing with the ultraminute, as we have seen. And man finds it quite as difficult to use his imagination effectively in this domain as he does in that of island universes. He can visualize fairly well dimensions related in magnitude to those with which he is familiar in everyday life, but at the extremes, both upward and downward, he has trouble.

Let us try to picture a particle with a theoretical radius of 10^{-13} centimeter. This is the method used by mathematicians to express a fraction whose numerator is 1 and whose denominator is the thirteenth power of 10. If we were to write the number out fractionally, it would appear as $\frac{1}{10,000,000,000,000}$, or one ten-trillionth, of a centimeter. (To get the true picture as nearly as possible, the reader must recall that a centimeter is about two fifths of an inch.) The compact and relatively massive nucleus, as we have previously noted, is about this size. Now the radius of the whole atom may be taken as 10^{-8} centimeter.[1] This means that the radius of the atom may be taken as a hundred thousand times greater than that of either the nucleus or the in-

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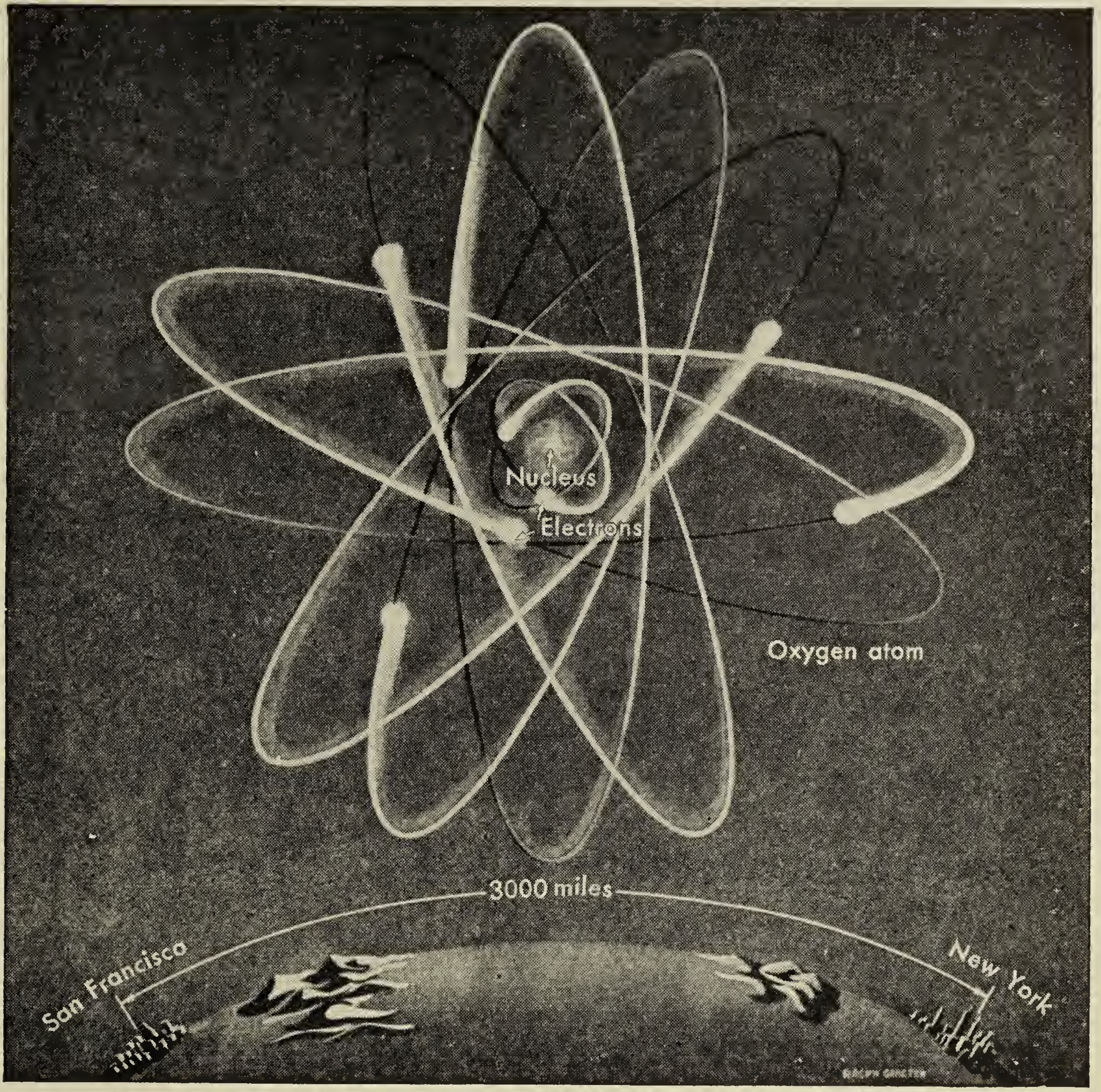
[1] Max Born, *The Restless Universe*, p. 175. (1936)



Life

Diagram to show space in the oxygen atom

dividual electrons that revolve about it. From this, relatively speaking, we get an idea, though an inadequate one, of the "dreary wastes" of space to be found within the atom.

To make the picture more vivid, a recent writer has used oxygen as an example. The atom of this element has eight electrons, each approximately the size of the nucleus and each revolving in its own orbit outside the nucleus. These orbits lie in different planes. If, now, the whole atom could be magnified to a scale that would make the nuclear diameter 1500 feet and the nucleus were placed at the center of the United States in an east and west direction, then the outer electron would pass through New York City and San Francisco at opposite ends of its orbital diameter.

These figures give us some idea of the relatively great space found within the atom. Indeed, if atomic dimensions were enlarged to the same scale as prevails among astronomical bodies, the distance between the electrons and the nucleus would be comparable to that found between the sun and its planets. Certainly Dr. Millikan was not far wrong when he referred to the atom as being "mostly hole."

Questions for Study

1. What was the old belief regarding the relationship of matter and energy?
2. What did Crookes discover that began to throw doubt upon the old conception of the atom?
3. Why did the discovery of X rays cause physicists to question further the older ideas of the nature of matter?
4. Why did Becquerel's work cause physicists to be even more skeptical of the older theory as to the structure of the atom?
5. How did the discovery of radium by the Curies contribute to the final downfall of the Newtonian theory relative to the structure of the atom?
6. What is the modern conception regarding the structure of the atom?
7. Why do astrophysicists believe the sun to be gradually decreasing in mass?
8. Did the new theory of the structure of the atom actually change that structure from what it was in Newton's day, or was it just man's conception of atomic structure that changed?
9. How may it be demonstrated that the electron has both electric charge and mass?
10. Are profound, epoch-making scientific discoveries usually the product of a single brilliant mind or the end link in a chain of preliminary, contributing minor discoveries?
11. How have X rays affected diagnosis and medical and surgical practice?
12. What scientific attitudes were exhibited in the steps that led from the older concept of the atom to the new?
13. What is the modern belief as to the nature of cosmic rays?

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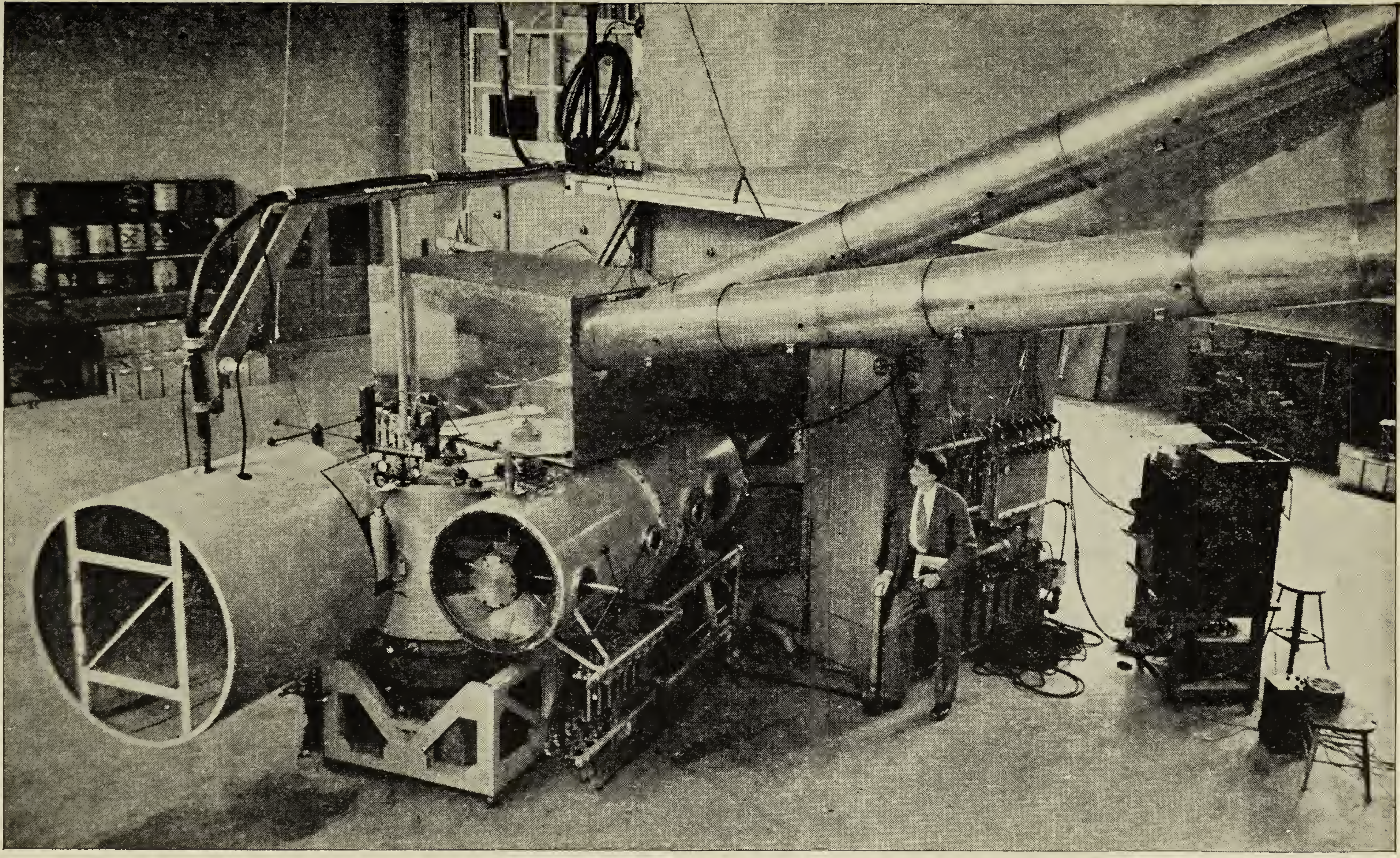
CHAPTER ELEVEN

Man Has Made Other Valuable Discoveries as to the Nature and Constitution of Matter

The Atom Has Proved to Be a Difficult Structure to Disrupt. In the previous chapter we found the atom to be a dynamic, porous structure. The nucleus at the center is extremely minute. Yet this diminutive nucleus not only contains practically all the mass of the atom, but, as the sun controls the planets, the nucleus also controls all the revolving planetary electrons. It has been made clear also that the atoms of all elements are, in a sense, but balanced electrical structures.

It must be evident that when alpha particles are used as the bombarding projectiles, the nucleus of an atom is an extremely hard target to hit. In the first place, the size of both the missiles and the targets is extremely minute; and in the second place, they both carry relatively heavy positive electric charges, which repel each other. In the heavier elements, which we shall presently find to have many positive charges on the nucleus, it is all but impossible, without special velocity-boosting mechanisms, to force an alpha particle inside this repelling barrier. For example, we find that when nitrogen gas is bombarded with alpha particles from radium, only about one in a million makes a nuclear hit. Neutrons, to be sure, which carry no charge and hence are not electrically repelled as they approach the nucleus, are better ammunition for atom-smashing. Unfortunately, however, they apparently are not emitted in radium decomposition, as we have found. For this reason, at the beginning, the shattering of atoms to see what they were made of was a slow process.

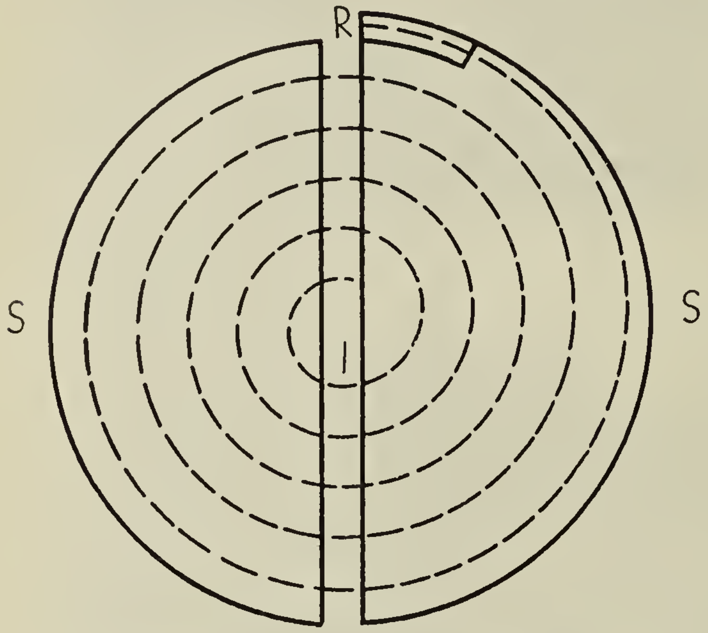
In their eagerness to hasten the process, physicists have devised ingenious mechanisms to lay down a heavier barrage of projectiles against the element whose atoms are to be disrupted. In fact, their fire as contrasted with that of radium, for example, is like the fire of a modern machine gun as contrasted with that of an ordinary rifle. There are different mechanisms of this sort; one widely used is the *cyclotron*. In principle the cyclotron is a device in which the particles to be used as missiles are made to travel within a magnetic field in an ever-widening spiral from the point of emission. By properly timed shifts in the high-frequency electric current, the electrodes under whose influence the particles move are made alternately negative poles and positive



Radiation Laboratory, Berkeley, California

A cyclotron

poles. Now if the particles being used are alpha particles, they will be pulled (attracted) by the poles when they are negative and pushed (repelled) by the same poles the instant they are made positive. Thus the moving particles are constantly accelerated in motion as they proceed on their way through their spiral path, much as a swing's motion is hastened by one who stands at the bottom of its arc and pushes it each time it goes by. At the end of the spiral flight the highly accelerated particles are directed against a portion of the element whose atoms are to be disrupted.



The path of the missiles in the cyclotron

I, the interspace between the charged sectors. *S*, *S*, the sectors in which the charge can be reversed. *R*, the place where the missiles are delivered

With this mechanism different particles may be used, such as alpha particles, protons, and deuterons. (The last are a special type of hydrogen nucleus containing both a proton and a neutron instead of a single proton.) The cyclotron gives its missiles a surprisingly high degree of energy, by which they are frequently able to penetrate the sphere of positive electrical influence, as represented by the nucleus. This may shatter the atoms immediately, knocking out of them such particles as protons, alpha particles, neutrons, or positrons; or the nucleus may capture the missile and disrupt later.

The reader is warned against the inference that atoms, even with the assistance of these powerful cyclotrons, can be shattered wholesale. There is too much space in them. The probability of missing the target altogether is too great. It is a good deal like shooting a powerful cannon ball out through the solar system at random with the purpose of hitting the sun. We are told that

> . . . if today's most efficient apparatus, adjusted to produce helium out of lithium and hydrogen, were operated continuously for 100 years, it could produce at the best only a fraction of a penny's worth of helium, whereas the power cost would approach $1,000,000. The physicist has not as yet learned how to produce new elements in bulk.[1]

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[1] Carl D. Anderson, "New Facts about the Nucleus of the Atom," *Annual Report, Smithsonian Institution, 1935*, p. 246.

Knowledge of the Structure of the Atom Makes It Possible to Arrange the Elements in an Orderly Series. The atoms of elements are not all of the same degree of complexity. Some have more protons and neutrons in the nucleus, and many more electrons outside the nucleus, than others. This knowledge led to many attempts to arrange the elements in an orderly system based on their structural and chemical relations. Earlier these efforts had been attended with some degree of success, but it remained for Henry Moseley, a brilliant young physicist in Oxford University, to discover the natural, logical sequence of the elements. To be sure, there were a few gaps where elements had not yet been discovered, but those that had been found fitted into this sequence admirably. Since the death of Moseley, all but two of the ninety-two elements believed to exist in nature have been discovered. These two have been reported, but there seems to be some uncertainty as to whether they have actually been found. As each new element was discovered, it fitted into a vacant place in the periodic table, just like a brick in the wall of a house.

Moseley's arrangement of the elements was based on the number of charges borne by the nucleus. As the nuclear charge increased, the complexity of atomic structure (that is, the number of protons, neutrons, and electrons involved) increased also. In this ascending scheme the atomic weight is equal to the sum of the protons and neutrons in the nucleus. Since the atom is an electrically balanced system, the number of positive charges on the nucleus, or protons, is always equaled by the number of electrons outside the nucleus. This being true, one may say that the numerical position of an element in the atomic series is indicated by the number of electrons outside the nucleus. Thus the hydrogen atom has one proton in the nucleus and one electron outside the nucleus. Then its atomic weight is 1, and its atomic number is likewise 1. Oxygen has a total of sixteen neutrons and protons in the nucleus and eight electrons outside the nucleus. Then its atomic weight is 16 and its atomic number 8, and so on for all the elements known. The table on page 164 shows the elements arranged in this order.

Many Elements Have Isotopes. It may be seen that the atomic weights are in many cases fractional, instead of whole numbers as one would expect from the explanation of atomic structure that has just been given. If the atomic weight is determined by the number of protons and neutrons in the nucleus, then the weight of an atom, it would seem, must always be expressed by an integer; for apparently protons and neutrons are never split up as they combine to form atomic nuclei. But the atomic weights of many elements when carefully determined are not whole numbers but fractional. For a time such results puzzled physicists and chemists greatly. Finally it was

Table of the Elements

Atomic Number	Element	Symbol	Atomic Weight	Atomic Number	Element	Symbol	Atomic Weight
1	Hydrogen	H	1.0080	47	Silver	Ag	107.880
2	Helium	He	4.003	48	Cadmium	Cd	112.41
3	Lithium	Li	6.940	49	Indium	In	114.76
4	Beryllium	Be	9.02	50	Tin	Sn	118.70
5	Boron	B	10.82	51	Antimony	Sb	121.76
6	Carbon	C	12.010	52	Tellurium	Te	127.61
7	Nitrogen	N	14.008	53	Iodine	I	126.92
8	Oxygen	O	16.0000	54	Xenon	Xe	131.3
9	Fluorine	F	19.00	55	Cesium	Cs	132.91
10	Neon	Ne	20.183	56	Barium	Ba	137.36
11	Sodium	Na	22.997	57	Lanthanum	La	138.92
12	Magnesium	Mg	24.32	58	Cerium	Ce	140.13
13	Aluminum	Al	26.97	59	Praseodymium	Pr	140.92
14	Silicon	Si	28.06	60	Neodymium	Nd	144.27
15	Phosphorus	P	30.98	61	Illinium	Il	?
16	Sulfur	S	32.06	62	Samarium	Sm	150.43
17	Chlorine	Cl	35.457	63	Europium	Eu	152.0
18	Argon	A	39.944	64	Gadolinium	Gd	156.9
19	Potassium	K	39.096	65	Terbium	Tb	159.2
20	Calcium	Ca	40.08	66	Dysprosium	Dy	162.46
21	Scandium	Sc	45.10	67	Holmium	Ho	164.94
22	Titanium	Ti	47.90	68	Erbium	Er	167.2
23	Vanadium	V	50.95	69	Thulium	Tm	169.4
24	Chromium	Cr	52.01	70	Ytterbium	Yb	173.04
25	Manganese	Mn	54.93	71	Lutecium	Lu	174.99
26	Iron	Fe	55.85	72	Hafnium	Hf	178.6
27	Cobalt	Co	58.94	73	Tantalum	Ta	180.88
28	Nickel	Ni	58.69	74	Tungsten	W	183.92
29	Copper	Cu	63.57	75	Rhenium	Re	186.31
30	Zinc	Zn	65.38	76	Osmium	Os	190.2
31	Gallium	Ga	69.72	77	Iridium	Ir	193.1
32	Germanium	Ge	72.60	78	Platinum	Pt	195.23
33	Arsenic	As	74.91	79	Gold	Au	197.2
34	Selenium	Se	78.96	80	Mercury	Hg	200.61
35	Bromine	Br	79.916	81	Thallium	Tl	204.39
36	Krypton	Kr	83.7	82	Lead	Pb	207.21
37	Rubidium	Rb	85.48	83	Bismuth	Bi	209.00
38	Strontium	Sr	87.63	84	Polonium	Po	210.00
39	Yttrium	Y	88.92	85	Virginium	?	?
40	Zirconium	Zr	91.22	86	Radon	Rn	222
41	Columbium	Cb	92.91	87	Alabamine	?	?
42	Molybdenum	Mo	95.95	88	Radium	Ra	226.05
43	Masurium	Ma	?	89	Actinium	Ac	?
44	Ruthenium	Ru	101.7	90	Thorium	Th	232.12
45	Rhodium	Rh	102.91	91	Protoactinium	Pa	231
46	Palladium	Pd	106.7	92	Uranium	U	238.07

discovered that different kinds of the same element often exist which have slightly different numbers of neutrons in the nuclei. These various types appear side by side in nature. They have similar chemical qualities, and their difference is detectable chiefly in their disparity of weight. Thus there are two kinds of chlorine, with atomic weights of 35 and 37. Since these isotopes usually appear mixed together in different proportions, the atomic weight of chlorine is found to be 35.457. Neon appears in two forms with atomic weights of 20 and 22. Since they occur in the ratio of about 9 to 1 respectively, the atomic weight of neon becomes 20.2. Hydrogen, instead of occurring with an atomic weight of only 1, has two other isotopes weighing respectively 2 and 3. The latter two are much rarer than the first, which pulls the atomic weight of this element up to about 1.0080.

When chemists and physicists discovered this new relation, the question followed, What shall we do with these substances that act alike but have different weights? Shall we call them different elements, or shall we regard them as different varieties of the same element? Professor Soddy presented a way out of the dilemma. He suggested that they be called "isotopes of the same element." The word *isotope* means "in the same place" and refers to their similarity of chemical behavior rather than to a similarity in weight. This plan was adopted, and these isotopes of the same element account for the fractional atomic weights that appear in the table.

Substances Have Been Made Radioactive Artificially. We have found that the discovery of radium was made by the Curies. It seems fitting that their influence should have continued in the scientific world through their daughter, Irène, and that she and her husband should have likewise made a great original, related discovery.

In 1934 Madame Irène Joliot and F. Joliot found that when many of the lighter elements, such as boron, aluminum, and magnesium, were bombarded with alpha particles, they continued to emit positrons for some time after the bombardment had ceased. This discovery was a brilliant achievement, for it will be recalled that up to this time the only radioactive elements that physicists knew anything about were the natural, spontaneous ones. But now the Joliots had actually succeeded in artificially creating one. If we use boron, for example, and let the exponent after the symbol of each element represent the atomic weight, and the subscript before each symbol represent the positive charge on the nucleus, we may represent the result as follows:

$$_5B^{10} + {}_2He^4 \longrightarrow {}_7N^{13} + \text{neutron}$$

$$_7N^{13} \longrightarrow {}_6C^{13} + \text{positron}$$

As indicated, when the boron nucleus is bombarded with the alpha particle from radium, it apparently captures the helium nucleus and emits a neutron. The net effect is to raise the nuclear weight of boron to the rank of an isotope of nitrogen with an atomic weight of 13 instead of 14, as in common nitrogen. But instead of being stable the new nitrogen isotope is unstable, and it was at this point that the new discovery was made, for it immediately behaved as an artificially prepared radioactive substance with a half-period of 11 minutes. By emitting a positron it reduced the nuclear charge to 6 instead of 7, and dropped from the nitrogen group to that of an isotope of carbon with an atomic weight of 13 instead of 12, the common atomic weight of that element. More than this, another new discovery had been made. That was that transmutations could result in the formation of a more complex element. All spontaneous radioactive decompositions, as well as those previously produced artificially, as we have noted, had proceeded from the more complex to the simpler elements. Now the process had gone the other way, and a more complex element had been created from simpler ones. Perhaps, after all, as some scientists have surmised, there are constructive, synthetic processes at work in the universe, as well as destructive, analytical ones.

This discovery of the Joliots was quickly confirmed by other workers in different parts of the world. Moreover, it has been found that many other elements, heavy as well as light ones, can thus be artificially rendered radioactive. It has also been ascertained that alpha particles are not the only effective projectiles that can be used. Protons, neutrons, and deuterons can likewise be effectively employed.

The range of elements that can be rendered radioactive artificially is being extended constantly. As Anderson says, "It now appears quite likely that any element by proper treatment can be prepared in a radioactive condition, and the years to come will undoubtedly find widespread tasks for them to perform."[1]

Uses of Artificially Produced Radioactive Elements. Almost since the discovery of radium it and other related radioactive elements have been used as therapeutic agents in connection with cancerous growths. The abnormal, rapidly growing malignant cells seem fortunately to be more susceptible to the lethal effects of these emanations than the normal cells. Accordingly many cases of cancer have been cured by this treatment. Particularly is this true with the more superficial and less deeply embedded tumors. But overexposed normal cells can also be permanently injured and are often killed by these radiations. This applies also to X rays, the hardest of which have extensively displaced the rare and more costly radium in medical practice. Consequently skill and careful technique have to be exercised in applying this therapeutic agent. As for the very deep malignant growths, it is almost impossible to irradiate them effectively without seriously burning the overlying tissues. Radium salts could be administered into the blood stream, but this element becomes fixed in the body tissues and is so long-lived that its emanations would doubtless prove disastrous to many normal organs.

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[1] Carl D. Anderson, "New Facts about the Nucleus of the Atom," *Annual Report, Smithsonian Institution, 1935*, p. 247.

For these reasons artificially produced radioactive substances hold great promise for the future of medical practice. Fortunately, so far as has been determined, they function in the metabolism of the body precisely as do the nonradioactive forms of the same elements. Let us take the element sodium as an example. If ordinary sodium is treated with deuterons, the missiles apparently are captured by the sodium nucleus. This intrusion sets up such a commotion among the internal constituents and forces of the sodium nucleus that a remarkable explosion ensues. In this disruption a proton and a higher isotope of the sodium are produced, and at the same time an intense gamma-ray activity is emitted. The process may be indicated as follows, exponential and subscript numbers being used as on page 165:

$$_{11}\mathrm{Na}^{23} + {}_{1}\mathrm{D}^{2} \longrightarrow {}_{1}\mathrm{H}^{1} + {}_{11}\mathrm{Na}^{24} + \gamma \text{ rays}$$
$$_{11}\mathrm{Na}^{24} \longrightarrow {}_{12}\mathrm{Mg}^{24} + \text{electron} + \gamma \text{ ray}$$

The new, heavy sodium isotope is unstable and decomposes after an average life of about 14.8 hours, resulting in magnesium, an electron, and a gamma ray. This radiosodium, as it is called, has a radioactive period long enough for it to be carried to all parts of the body before its electron barrage is spent.

Unstable, and hence radioactive, isotopes of different elements as they explode emit different kinds of particles, such as positrons, electrons, and alpha particles. The half lifetime of many of these radioactive elements is too short to be of value, but others have a half lifetime of many days and, in a few cases, of several years.

These artificially produced radioactive elements hold great promise for the future, not only in medicine but in the study of the physiological functions of both plants and animals. They are now being used in the direct treatment of various diseases. The results in certain diseases, such as leukemia, in addition to cancer, are reported to be distinctly encouraging.

Artificial radioactive substances also give promise of being of great value in physiological studies. For instance, bone formation in rats appears to be a continuous process within the body and not one limited to the growing period of youth. Danish scientists working with these experimental animals at the Finsen Hospital in Copenhagen have discovered that 30 per cent of radioactive phosphorus atoms deposited in the skeleton of an adult rat was removed in the course of 20 days, and that the front teeth absorbed ten times as much phosphorus as the average for the skeleton. The radioactive phosphorus naturally went about throughout the body "broadcasting" its emanations, so that its presence and quantity in the different organs could be determined at any time.

Artificial radioactive elements (they are often called "tagged" or "tracer" elements), such as calcium, iron, iodine, and others, are being used to study the disposition made of them by the body once they are taken into the alimentary canal or injected into the blood stream. In experiments with dogs at the University of Rochester iron began to show up in the hemoglobin of the red blood corpuscles four hours after being fed. Human hyperthyroid patients at the University of California medical school showed a deposit of about 14 per cent of tagged iodine in from one to four hours. By introducing a tracer element into the molecular structure of vitamin B_1 investigators at the latter school have initiated studies designed to show the functional activity of this nutritional requirement in the body.

Hamilton rendered the sodium in ordinary table salt radioactive by bombarding it with deuterons. An experimental volunteer drank water containing this salt. He took a sufficient quantity to introduce into his system radiosodium equal in radioactive properties to about 0.0005 gram of radium. With the subject's hand protected by a sheath of lead to shield off rays from other parts of his body, it was found that in about two minutes after drinking, the Geiger counter, which is an instrument used to detect radioactive emanations, began to click. This indicated that in this short period of time the ions of sodium had been absorbed into the blood stream and had reached the finger tips. The radioactivity in the hand rose steadily for about three hours, when it reached its maximum.

Atoms Unite to Form Molecules. In this and the previous chapter we have centered our attention on the nature of matter as revealed by atomic structure and the shifts which take place within the nucleus. We have found atoms to be extremely minute but highly complicated structures. Moreover, atoms possess an extreme tendency to be "sociable." If they can, they always associate either with their own kind or with other kinds of atoms to form larger groups called molecules. These atomic groups hold together with great tenacity and in general cannot be made to disband without the application of considerable energy. In some substances the atoms in the molecule are loosely joined together and can be made to separate quite easily, but this is not the rule. When the atoms are securely bound together in the molecule, the chemist speaks of the substance as being *stable*; when they are loosely conjoined, he expresses this relation by saying the substance is *unstable*.

Although larger than atoms, molecules too are almost incomprehensibly small. Millikan says that the number of molecules in a given volume or weight of any homogeneous substance can be counted with greater precision than we can count the population of a city or a state. He estimates the number of molecules in a cubic centimeter of air at 27.05 billions of billions, or, to express it in figures, 27,050,000,000,000,000,000.

Our idea of the molecular population of a substance becomes still more vivid if we say that if an opening were made in the side of an ordinary electric-light bulb of such a size that the molecules of air could crowd in at the rate of one million a second, it would take a hundred million years for them to fill the bulb.

Molecules, like atoms, are believed to have much space between their component parts (the atoms). In addition, there is thought to be, in the ordinary substance, considerable intermolecular space. One author has tried to picture the intermolecular space by saying that if the molecules of air at room temperature were represented by baseballs, there would be 75 feet of space about each ball. Therefore, with great expanses of space between the constituents of the atom, much between the components of the molecules, and much between the molecules themselves, one can see just how porous matter really is. One marvels when he considers the stable, resistant, and substantial character of many substances which apparently are so sparsely built.

Questions for Study

1. How has man's notion of the atomic relationships of the elements been affected by the use of X-ray spectra?
2. How did the discovery of neutrons change man's conception of atomic structure?
3. How has the modern theory of the structure of the atom given new significance to the periodic table?
4. How can you harmonize the fact that the mass of protons, which determines atomic weight, is a whole number but that the atomic weight of an element as given in the atomic-weight table is usually a fractional number?
5. Do the different isotopes of an element represent chiefly a physical or a chemical difference?

6. How has the theory that matter was immutable fared as a result of the new physics?

7. How may radioactive elements be artificially produced?

8. How may artificially produced radioactive elements be employed in physiological studies?

9. Upon what principle does the "radium hound," a device to locate lost or misplaced radium, work?

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UNIT THREE

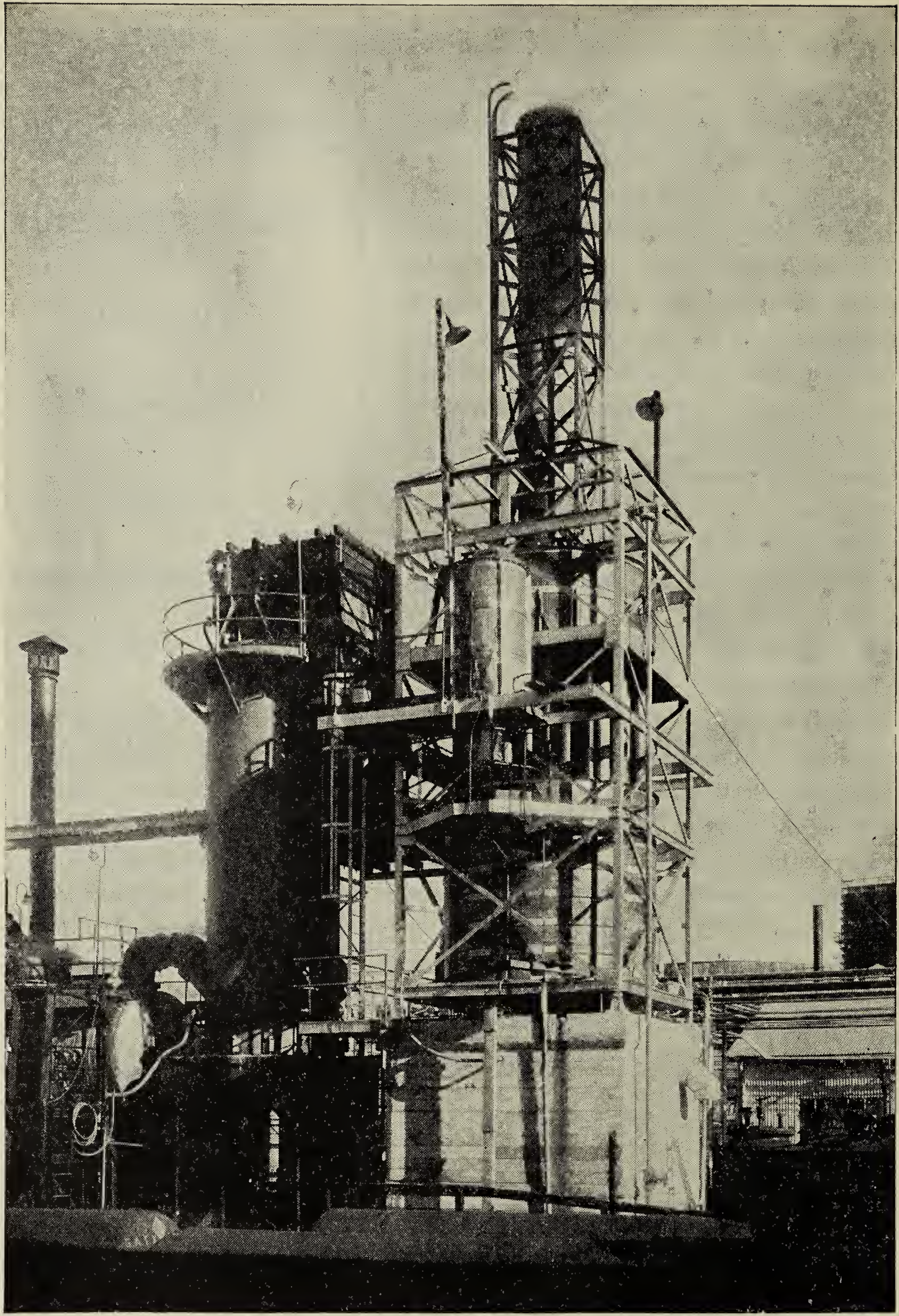
Matter as Organized Energy Possesses Properties Which Are Indispensable to Man

In *Unit II* it was found that fundamentally matter is but a pattern of organized energy. Nevertheless, in practical affairs, we are compelled to deal with matter as if it were something quite different from energy. It makes little difference in everyday life whether the atom is regarded as a unit of organized electricity or as a minute but hard and impenetrable body. An unsuspected open door in a dark room is just as damaging to one's nose in either case, and a tree in the pathway of a careening automobile is just as destructive.

Despite the new concept, matter occupies space; it may take the form of a liquid, a gas, or a solid; and solids retain the same tough and durable properties that made them indispensable to the Greeks and Babylonians.

Even if we persist in the older "matter point of view" instead of the newer "organized-energy concept," we still cannot set up the same hard-and-fast dividing wall between matter and energy that the older physicists maintained. For when they came to explain the nature of chemical change or to define the forces that hold atoms together to form molecules, they were baffled. In the light of modern views, however, chemical reactions and intramolecular forces become quite intelligible.

In this unit we shall deal to some extent with both the old and the new concept, for we shall consider matter in relation to both its physical and its chemical properties.



Western Precipitation Corporation

An acid-mist precipitator in use by a chemical company (see page 231)

CHAPTER TWELVE

Matter May Be Changed from One State to Another

The States of Matter Depend upon Molecular Relations. One state of matter may be converted into another by changing conditions of temperature and pressure. Indeed, it is probable that if one could control temperature sufficiently, this factor alone could be made to effect the desired transformations. For example, grain alcohol in the liquid state may be readily transformed into vapor by the application of heat. The added heat increases the speed of the molecules and thus forces them farther apart. If, on the other hand, alcohol be subjected to a sufficiently low temperature, it will freeze and become a solid. Some elements are much more difficult to change from one state to another than is alcohol. But by either adding heat to force the molecules apart or withdrawing it to bring them closer together, the desired transformation may be accomplished. The different states of matter are determined by but one condition: *the relation which the molecules bear to one another.*

The Properties of Gases Are Due to the Loose Arrangement of the Molecules. In gases the molecules are relatively far apart. In the air of a living-room, for instance, the molecules of oxygen and nitrogen are, on an average, about eight times their length apart. They are so distant from one another that the mutually attractive force called cohesion is negligible. In the other states of matter cohesion is a very evident force, especially so when we consider the amount of work required to hammer, plane, saw, or stretch a solid body; but in gases the molecules appear to be relatively free, going their own way and jostling one another about like people in a crowd. Under normal conditions they are always on the move. They dart here and there, going in straight lines until they collide with one another or with some other object. Then they are deflected into another course, which they pursue until still another collision occurs. Indeed, this state of molecular motion is not a property of gases alone, but exists in liquids and solids as well. However, under the latter conditions the molecular motion is much more restricted than it is in gases.

Recognition that the molecules of matter are in a state of constant motion has led to a very important principle in physical science. This generalization is known as the *kinetic-molecular theory of matter.* The form of energy which appears as molecular motion is heat. Cool a body, and the degree of molecular agitation falls. Heat it, and the molecular movement is speeded up. As a cool stove is heated to incandescence, the dance of the molecules grows so violent that light waves are sent out through space. It is for this reason that the stove looks red.

The molecules which comprise the air at surface density move at an average speed, in the summertime, of about 1500 feet per second and suffer about 250,000 collisions in going an inch. Molecules of hydrogen, being lighter than the molecules of air, travel four times as fast as the average speed of the molecules of air. To follow this principle further, it is the ceaseless bombardment of the sides of a container by the molecules of a gas that makes the confined gas exert pressure. When one tries to compress an inflated bag or a toy balloon, his hand meets with a great deal of resistance. This resistance is produced by the molecules beating against the inside of the bag or balloon.

The force of the enclosed bombarding molecules (the gaseous pressure) can be increased in two ways: either by reducing the volume and hence compressing the number of molecules into smaller space, or by heating the enclosed gas and at the same time keeping the volume constant.

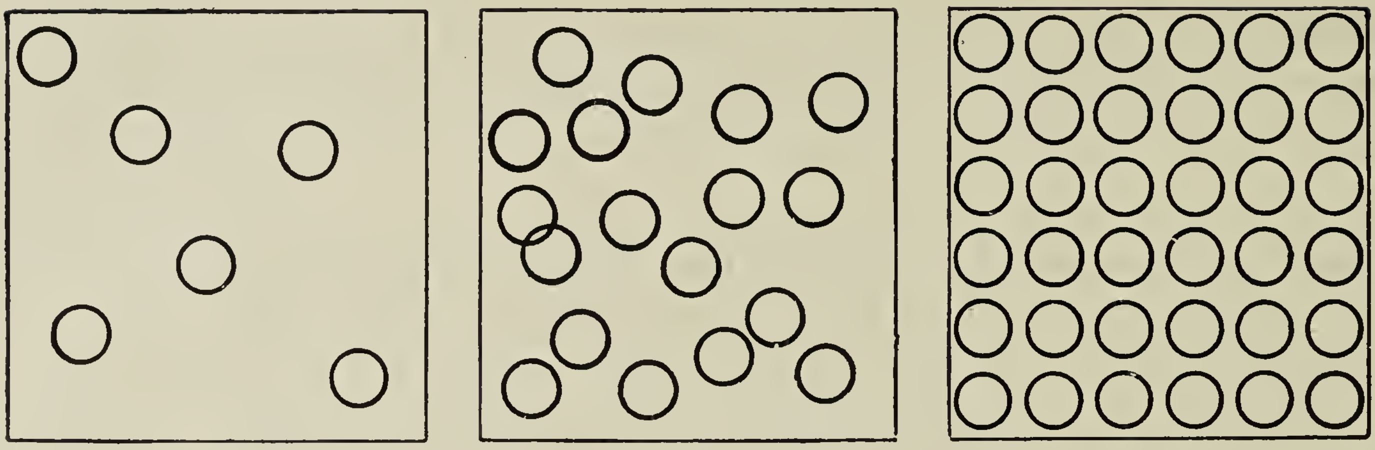
Boyle's Law. Robert Boyle, a distinguished Irish scientist born in 1627, discovered a very important law. It is true within the limits of everyday application and may be stated simply as follows: *The volume of a given quantity of gas, provided the temperature remains constant, is inversely proportional to the pressure exerted upon it.* In other words, if one increases the pressure on a volume of gas at constant temperature, he decreases its volume commensurately. On the contrary, if he decreases the pressure, the gas promptly expands in the same ratio. For example, when one forces air into an automobile tire, he decreases its volume but increases the pressure within the tube. This results from the increased number of impacts made against the wall of the tire by the molecules of air, which are crowded more closely together. Assuming the same temperature, if one crowds twice as many molecules into the tube, he will double the pressure because the walls of the tube are now receiving just twice as many impacts as before.

Charles's Law. Jacques Charles was born over one hundred years later than Boyle. He was a balloon enthusiast, and under his direction the first hydrogen-filled balloon was raised. This bold navigator of the air became interested also in the expansion of gases and as a result discovered the law that bears his name. Charles did not publish the results of his studies. Gay-Lussac, however, another Frenchman, discovered the same principle and did publish his findings, so that the law is not infrequently referred to as the law of Gay-Lussac. It may be stated, for practical purposes, as follows: *Under constant* *conditions of pressure, the volume of a gas varies in proportion to its absolute temperature.* We shall find in a subsequent section (p. 283) that, under constant pressure, as the temperature of a gas falls from 0° to −1° C, its volume decreases about $\frac{1}{273}$, and as the temperature rises above the zero point, the volume increases correspondingly. In the latter change energy in the form of heat is applied, and the agitation of the molecules becomes more violent. Hence they beat against the sides of their enclosure with more force and exert more pressure. Thus, if a toy balloon filled with gas is heated, it expands. Likewise the pressure in an automobile tire is increased on hot summer days without the addition of more air. Hard driving further increases the vibrational velocity of the molecules within the tire because of the heat developed by friction. Automobile-drivers in very hot weather, particularly in sandy deserts, often partially deflate their tires in order to lessen the danger of blowouts. On the other hand, as cool autumn weather approaches, the pressure in an automobile tire becomes appreciably less. Because of the loss of heat, the energy of the molecules is reduced, they move less vigorously, and the pressure in the tube falls commensurately.

Liquids Result from Important Molecular Relations. Liquids, such as water, alcohol, and gasoline, are also aggregates of molecules. Liquids, however, contain far less intermolecular space than gases. In a liquid like water the molecules are computed to be only about their own breadth apart, instead of eight times their length apart as was found for the gases of the air. The molecules of a liquid also move with great speed, but not so fast as those of a gas. At room temperature molecules of water move with an average velocity of over 35 miles a second. Of course they never actually travel so far in a second. Constant collisions with other molecules prevent it. It is estimated that at room temperature a molecule of water averages about two trillion collisions a second.

The molecules in a liquid are so compact that they can be compressed very little; yet they move about readily, and easily accommodate themselves, under normal conditions, to the contour of a bottle or any other container in which they may be placed.

The average distance between the molecules of a liquid may be increased by applying heat. For instance, if water in a vessel is placed over a fire, as the temperature rises the agitation of the molecules becomes more violent. By the addition of heat the molecules are driven farther and farther apart. At the surface, the hottest molecules, and hence the most rapidly moving ones, may dart so far as to fly entirely outside the range of the effective cohesive pull. Thus the molecules enter the gaseous state and go darting off as particles



Gases Liquids Solids

Diagrams to illustrate the molecular relations in solids, liquids, and gases

of water vapor. It is for this reason that heating water makes it vaporize more rapidly. It is also for this reason that laundered clothes or muddy roads will dry much faster on a warm day than on a cold one.

If heat continues to be applied to the vessel, all the water will presently be transformed into vapor. When this has been accomplished, it can be found by measurement that every cubic centimeter of water when vaporized expands to a volume of about 1600 cubic centimeters. This reveals concretely how much farther apart the molecules of a gas are than those of a liquid.

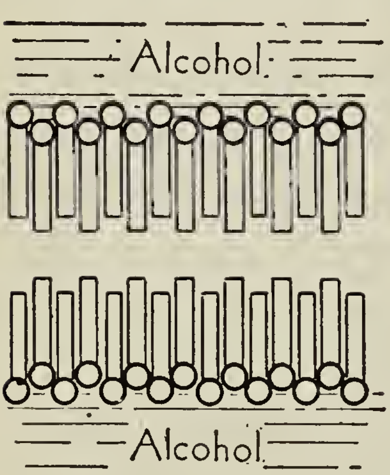


Diagram to illustrate the arrangement of molecules at the surface when a column of alcohol is separated

On the other hand, if water in a container is cooled (heat is given up), molecular action slows down, and the molecules come closer together. At about 4° C contraction ceases, the volume begins to expand, and finally at 0° C the liquid solidifies into ice. Now the molecules have lost all properties of a liquid and have taken on those of a solid—all because of a change in molecular relation and motion.

Surface Tension Is Important in Everyday Life. Liquids behave as if they were covered with a stretched elastic skin. This property is known as surface tension. Physicists tell us that surface tension is due to the unbalanced cohesive pull on the surface molecules (see figure above). Because of this unbalanced pull, the molecules are often condensed, or "packed," at the surface. If the molecules are longer in one dimension than the other, as they not infrequently are, they may even be pulled up on end by this unbalanced attraction and appear somewhat like a layer of tightly packed cigars standing on end (see figure above).

By careful manipulation one may place a needle on water and make it float, although steel is much heavier than water and ordinarily sinks. The needle is borne up by the tough outer skin of packed water molecules. Many insects utilize the surface tension of water in carrying out their ordinary life activities. Whirligig beetles go skimming over the surface of water like skaters on ice, seizing here and there tiny objects of food and escaping enemies.

It is possible, because of surface tension, to drop "eye drops" from a medicine-dropper into the eye. Were it not for this force, the medicine would issue in a fine stream; but the surface tension pulls the liquid into globular form. If one turns a water faucet down slowly, the stream ultimately becomes so small that it breaks up into droplets because of the surface tension of the water. For this reason, too, as well as others, rain falls as raindrops.

Different liquids vary widely as to the strength of their surface tension. Mercury has a very high surface tension. Consequently, if mercury is accidentally spilled, it goes flying over the surface of the floor as a flock of different-sized beadlike drops. The molecules of mercury in these drops are so securely held together by the force of surface tension that they will scarcely alter their form and flow into a small crevice. On the other hand, there are some liquids which have a very low surface tension. One of these is hexylresorcinol, often sold as an antiseptic. Equal-sized pipettes of water and hexylresorcinol taken from containers in the same refrigerator showed 22 drops for the former and 53 for the latter. The drops of the hexylresorcinol are smaller because the surface tension is too feeble to hold a large drop against the pull of gravity. This same preparation is often called S.T. 37, which means "surface tension 37 dynes per square centimeter." Such a surface tension is a very low one; and one of the merits claimed for this antiseptic as a nose and throat wash is that its low surface tension permits it to flow readily into the tiny crevices and folds of these passageways.

A rise in temperature reduces the surface tension. A pipette of ice-cold water gave 25 drops, but the same pipette filled with boiling water produced 35 drops. It is partly for this reason that hot-water molecules will move between the particles of wood and cause a leaky barrel to swell and become watertight much more quickly than cold water. Also partly for this reason, hot gargles for the throat, such as salt or soda in hot water, are better than cold ones.

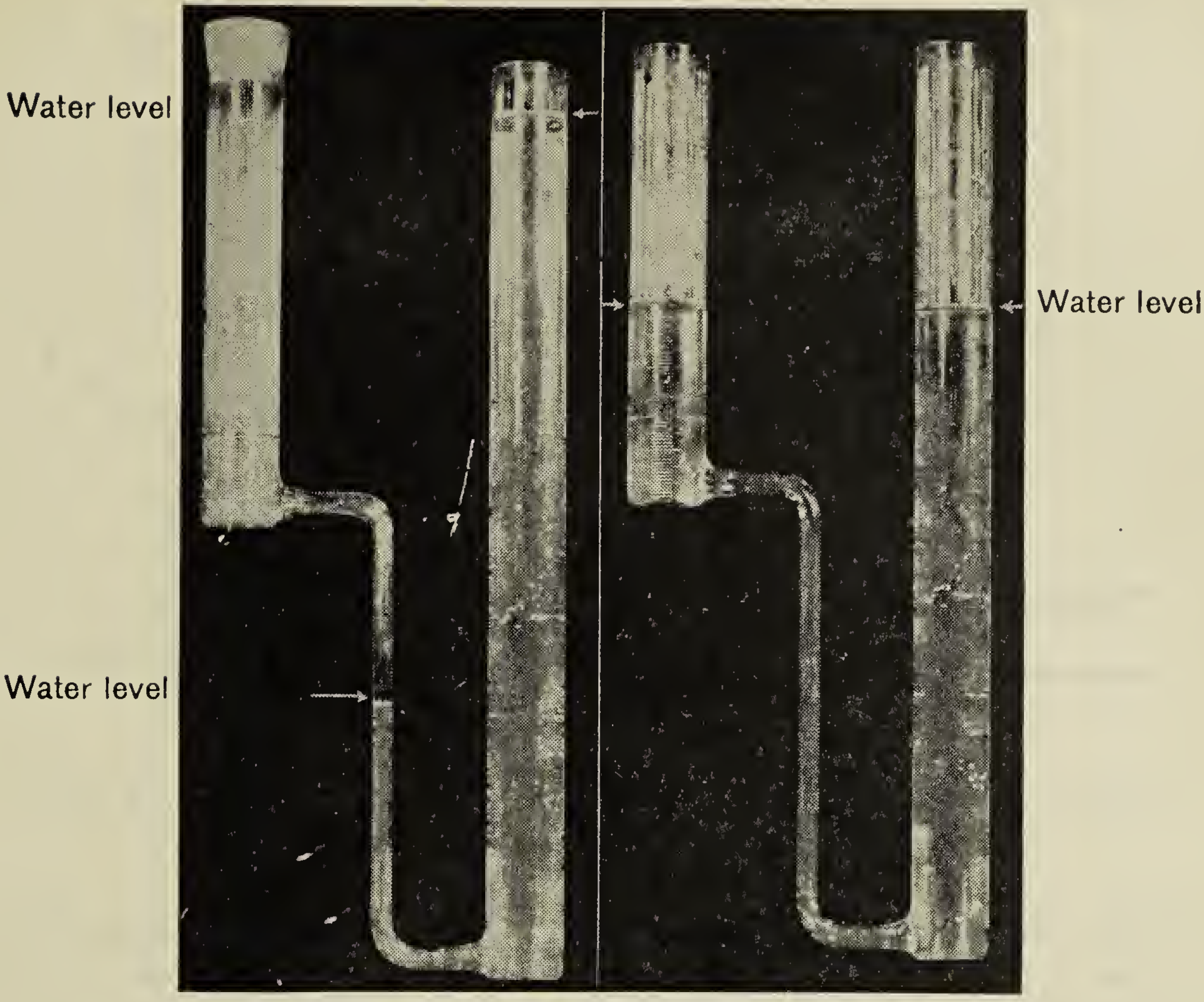
Fluids Have Properties That Are Important in Everyday Experience. Gases and liquids have many characteristics in common. Perhaps the most striking of these is that, under ordinary conditions, they both flow readily. For this reason they have been grouped together and called fluids, a term which means anything that flows. As substances that flow, fluids enter into the life of man and the processes of the world in a very important way.

Fluids Readily Diffuse. If one could seal the living-room of his own home airtight and hold the temperature constant, so that there would be no convection currents to stir up the atmospheric gases, he would then have the setting for a most interesting experiment. By introducing at one corner of the room an open pint jar full of ammonia gas, for example, an interesting phenomenon would occur. We have previously found that the molecules of a gas are in a state of constant agitation and that there is little cohesion between them to hold them together. For this reason molecules of the ammonia gas, leaving their fellows, would jostle out through the air, and the air molecules likewise would tend to move among the ammonia molecules. If the room were left undisturbed long enough, it would be found that the ammonia-gas molecules had distributed themselves evenly among the gas molecules of the atmosphere. In other words, there would be just as many ammonia molecules in a cubic centimeter of air taken in a sample from the opposite corner of the room as there would be in a similar sample taken from the corner in which the gas was originally introduced. This phenomenon of molecules moving out spontaneously among other molecules is known as *diffusion.*

It will be readily recognized that diffusion depends upon the kinetic condition of the molecules. The molecules move among one another because they are in a state of constant motion and collision. If wind and convection currents, which are mass movements of the air, are disregarded, it is for this reason that one can smell the perfume of a wild plum tree or a blooming rose. Were it not for diffusion, our perfume manufacturers would have to go out of business. Worst of all, perhaps, half the pleasure of eating would be lost; for physiologists tell us that a large part of the pleasant flavor of foods is a matter of smell rather than taste.

Liquids and solids too, to some degree, manifest the property of diffusion. Here, however, whether or not diffusion occurs depends on whether there is a greater attraction between the like molecules of a substance or between the molecules of the diffusing substance and those of the substance into which diffusion is taking place. In the former case diffusion will not occur to any appreciable degree; in the latter it will. Bluing readily diffuses into the rinse water in the laundry, and dyes mix easily with the solvent in which they are to be used; but mercury will not mix with water, nor will water diffuse into a film of oil floating on its surface.

Liquids Exert Hydrostatic Pressure. Liquids exert hydrostatic (Greek *hydro*, from *hydor*, "water," plus *statikos*, "causing to stand") pressure. This term was applied because the first fluid studied in this respect was water. It was observed that when water is piled up deeper at one point than at another,

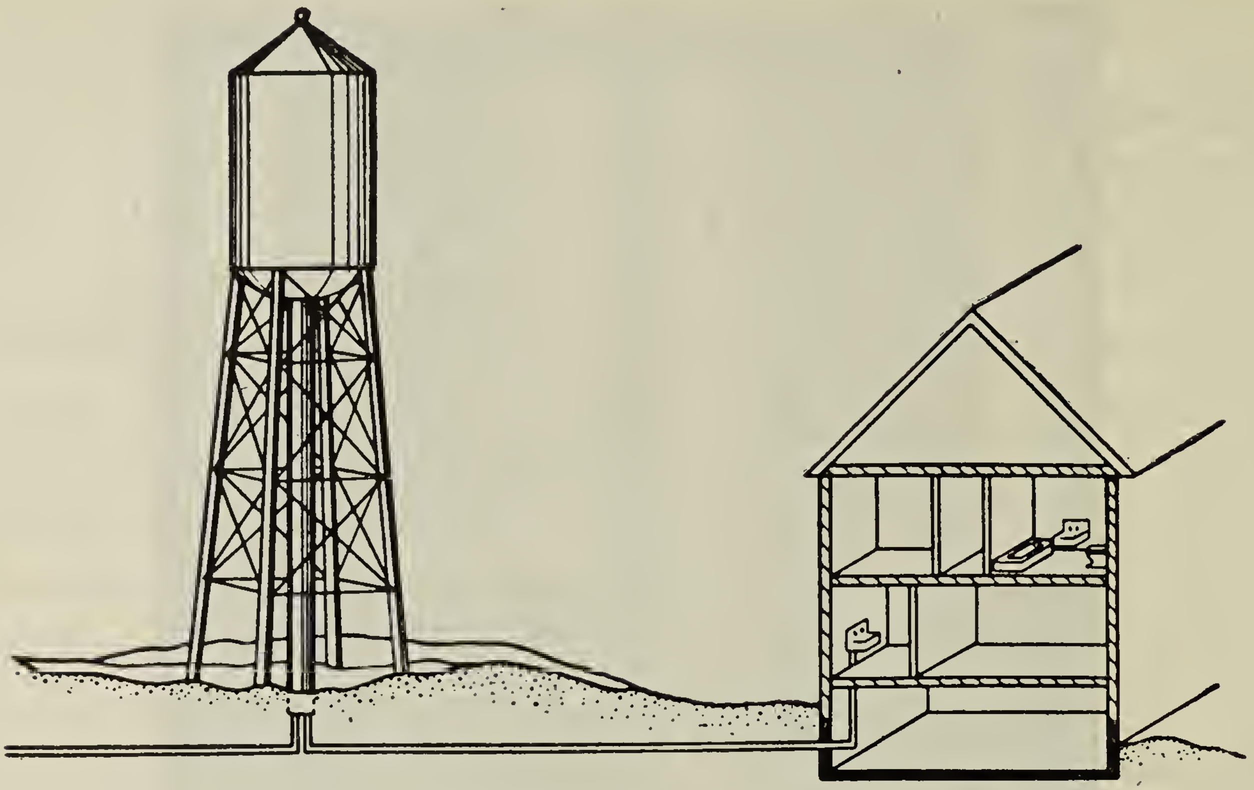


Water tends to seek the same level

Left, water level is unequal; right, when stopper is removed, the water level in both tubes becomes equal

the higher portion exerts a pressure upon the lower and a state of equilibrium results when the two surfaces have reached a common level (see above). The intensity of the hydrostatic pressure may be expressed as pounds per square inch and obviously depends upon both the height of the water and its density. For small differences of level the difference of pressure is not great, but for high columns of water it becomes enormous. At a depth of 100 feet, the pressure is more than 43 pounds per square inch. Men who work deep beneath the water's surface, preparing abutments for bridges, have to work in caissons under high air pressure to hold the water out.

It is this ability of liquids to exert hydrostatic pressure that makes possible gravity-pressure water systems. In these systems the supply is elevated in a reservoir or standpipe many feet above the point of use. Hydrostatic pressure now forces the water down into pipes which supply commercial establishments and private homes. In most cities the same system also supplies water to be used by the fire department. The pressure available for this service must be a rather high one; hence the need for a standpipe or elevated reservoir.



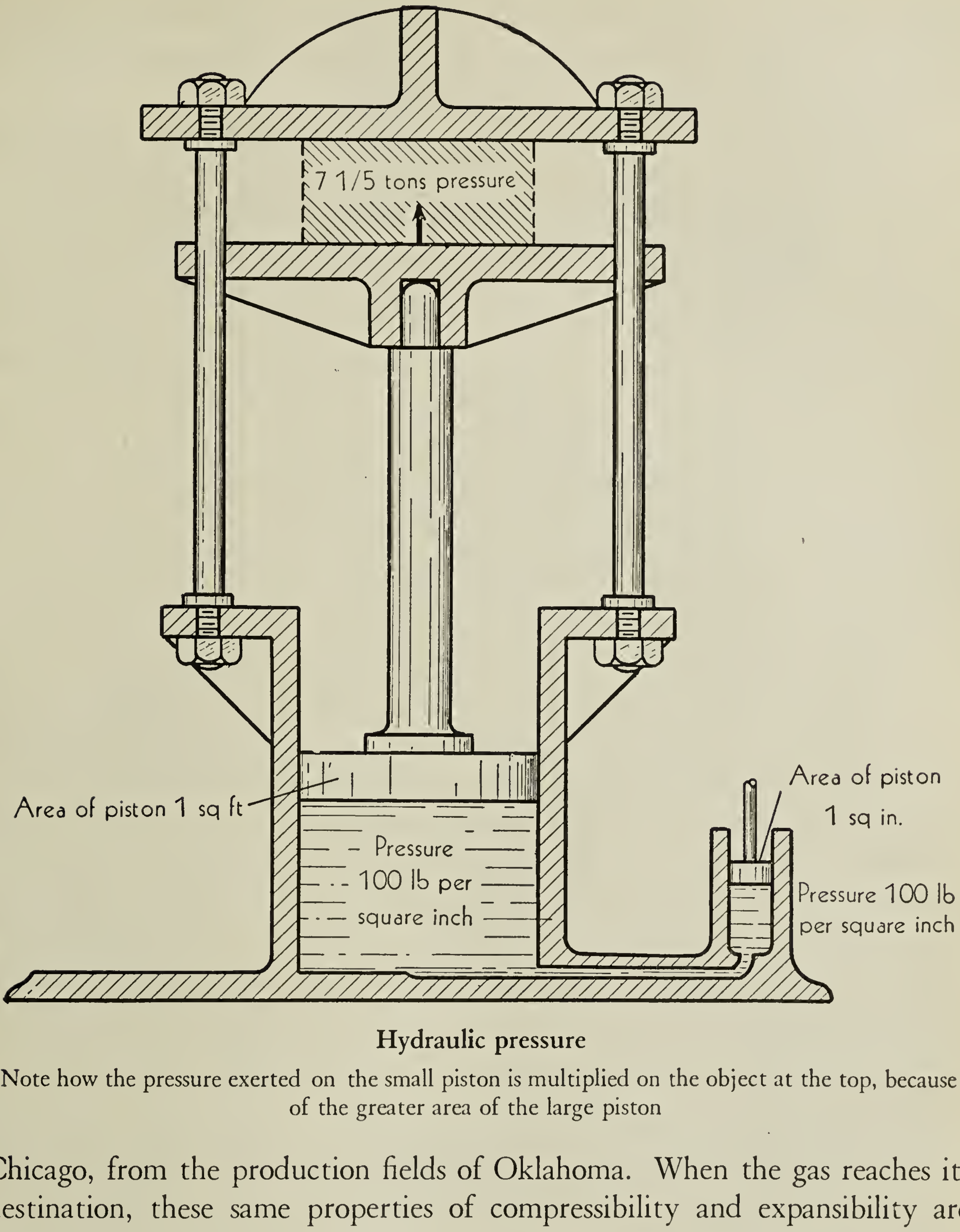
A gravity water system

Water in the elevated tank, tending to reach an equal level in the house, exerts a pressure at all the faucets

Hydrostatic pressure is exerted equally in all directions. A gauge placed on a large water main shows practically the same pressure regardless of whether it is attached to the top, bottom, or side of the main. This property of hydrostatic pressure applies to all liquids and is of great value in many ways. It makes possible the modern hydraulic automobile brake (see page 186). Hydraulic jacks used to raise buildings and other heavy objects depend on the principle of hydrostatic pressure for their effectiveness.

Closely akin to hydrostatic pressure is gas pressure. Gases, as we have found, have much more space between the molecules; hence they are much more compressible than liquids. For instance, the molecules of the air are piled on one another from the surface of the earth up as far as any atmosphere of appreciable density extends. This distance has been estimated to be 200 miles. The weight of the superposed molecules exerts great pressure on the layers next to the earth and compresses them. It has been computed that fully half of the earth's total atmosphere, owing to this compression, lies within the first 3½ miles. The result is a sea-level atmospheric pressure of 14.7 pounds per square inch exerted in all directions.

Compressibility and Expansibility Are Important Characteristics of Gases. We have already noted the compressibility and expansibility of gases in connection with the inflation of automobile tires. The vast stores of natural gases used for cooking and heating in the Middle West are transported through pipe lines under pressure to Denver, Cheyenne, Omaha, Kansas City, and


7 1/5 tons pressure
Area of piston 1 sq ft
Pressure 100 lb per square inch
Area of piston 1 sq in.
Pressure 100 lb per square inch

Hydraulic pressure

Note how the pressure exerted on the small piston is multiplied on the object at the top, because of the greater area of the large piston

Chicago, from the production fields of Oklahoma. When the gas reaches its destination, these same properties of compressibility and expansibility are employed to carry it through the distributing lines to private homes.

Breathing is also dependent upon the compressibility and expansibility of gases. By muscular contraction the diaphragm is lowered and the ribs are raised, which increases the lung space, allowing the enclosed air to expand. This action tends to cause a decrease in pressure within the chest. Immediately the air rushes in until the pressure is equalized. In this manner the multitudinous air vesicles of the lungs are filled, and the oxygen–carbon dioxide exchange necessary to support life is made possible. Once this exchange has been effected, muscular contraction raises the diaphragm and contracts the ribs, thereby forcing the vitiated air out of the lungs.

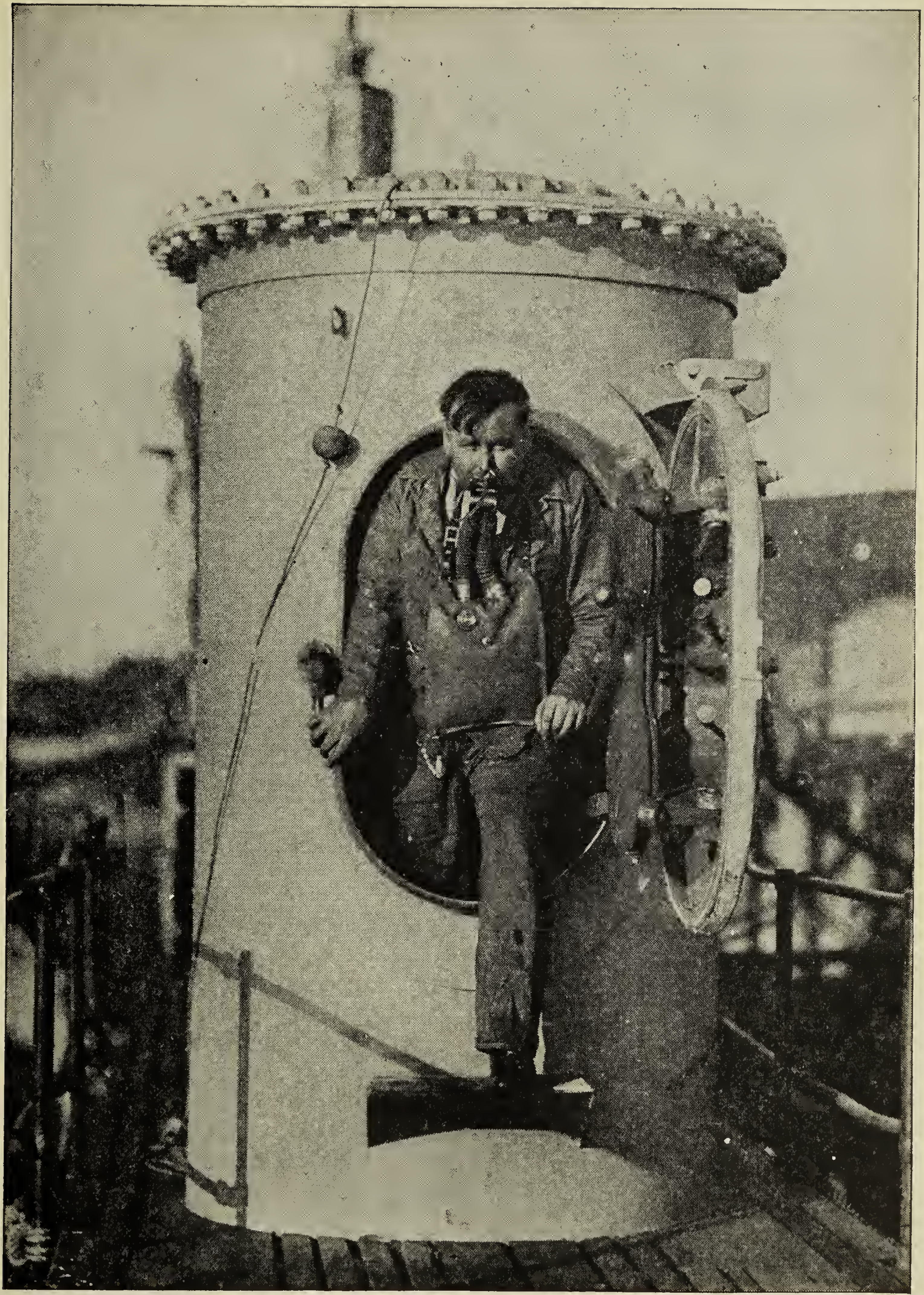
Atmospheric pressure is utilized in the sealing of canned foods. In the case of vacuum-packed products, as well as home-prepared cold-pack fruits and vegetables, the airtight sealed condition of the lids is maintained not so much by their "tightness" as by the pressure of the atmosphere on the outside. This is clearly seen from the fact that a stubborn can or bottle lid may be readily removed once a vent has been made to admit the air and thus equalize the inside and outside pressures. The pressure exerted by the atmosphere on the water in a well forces the water up into the cylinder of the pump as the piston is raised by a downward stroke of the handle.

Fluid Pressure Produces Buoyancy. Archimedes was a famous Greek scientist who lived in the third century before the Christian Era. He was requested by King Hiero to determine whether a crown professed by its maker to be pure gold was genuine or whether it was alloyed with silver. In the primitive state of science of that day no technique had been developed by which this determination could be made. Archimedes pondered intently over the matter, and, as the story goes, the solution occurred to him one day while in his bath. The principle discovered was this: *Bodies submerged in fluids are buoyed by a force equal to the weight of the fluid which they displace.*

The principle involved is that of hydrostatic pressure. All sides of an immersed body are pressed upon. But the top of the body is pressed upon with less force than the bottom. The difference in pressure is equal to the hydrostatic pressure of the displaced fluid, or in other words to the weight of the displaced fluid. Consequently, if an immersed body has a density less than that of the fluid, it will float; if greater, it will sink. But the weight of a body that sinks will be reduced by an amount equal to the weight of the fluid which is displaced.

The principle of buoyancy has wide application. The specific gravity of the acid solution in an automobile storage battery varies with its degree of exhaustion. By using a hydrometer the condition of the battery may be determined. The strength of the antifreeze solution in the radiator is ascertained in a similar manner. The density of salt brines may be determined in the same way.

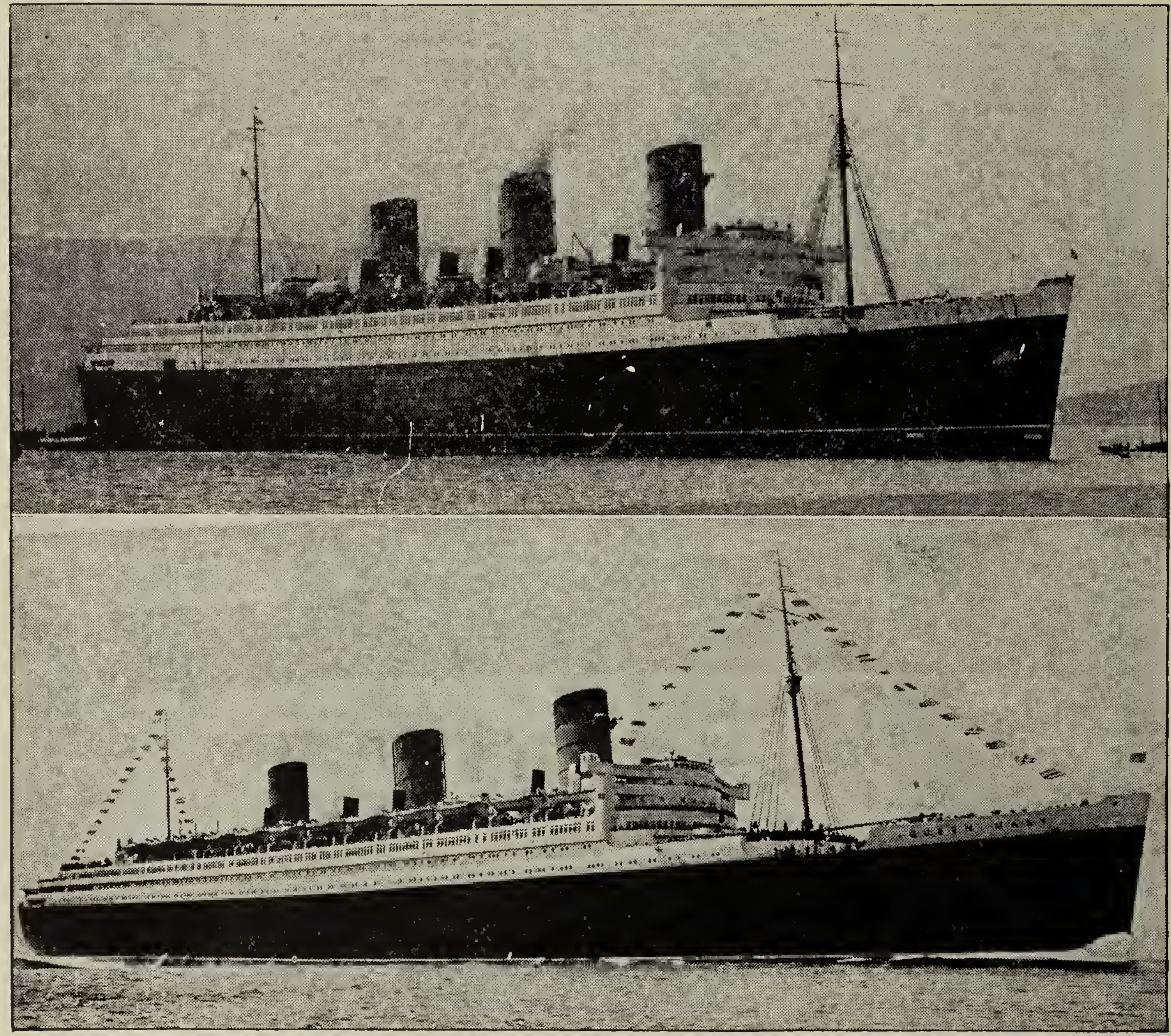
In the commercial world the principle of buoyancy is an important one. Navigators determine the safety limits of a ship's cargo by the amount of water displaced by the ship; submarine boats rise or submerge by varying the amount of water in their submersion chambers. Balloons rise or sink according to the density of their included gases. Airplane-operators, when



Underwood & Underwood

A submarine rescue chamber

Such a device must be very strong to withstand the pressure exerted on it by the water



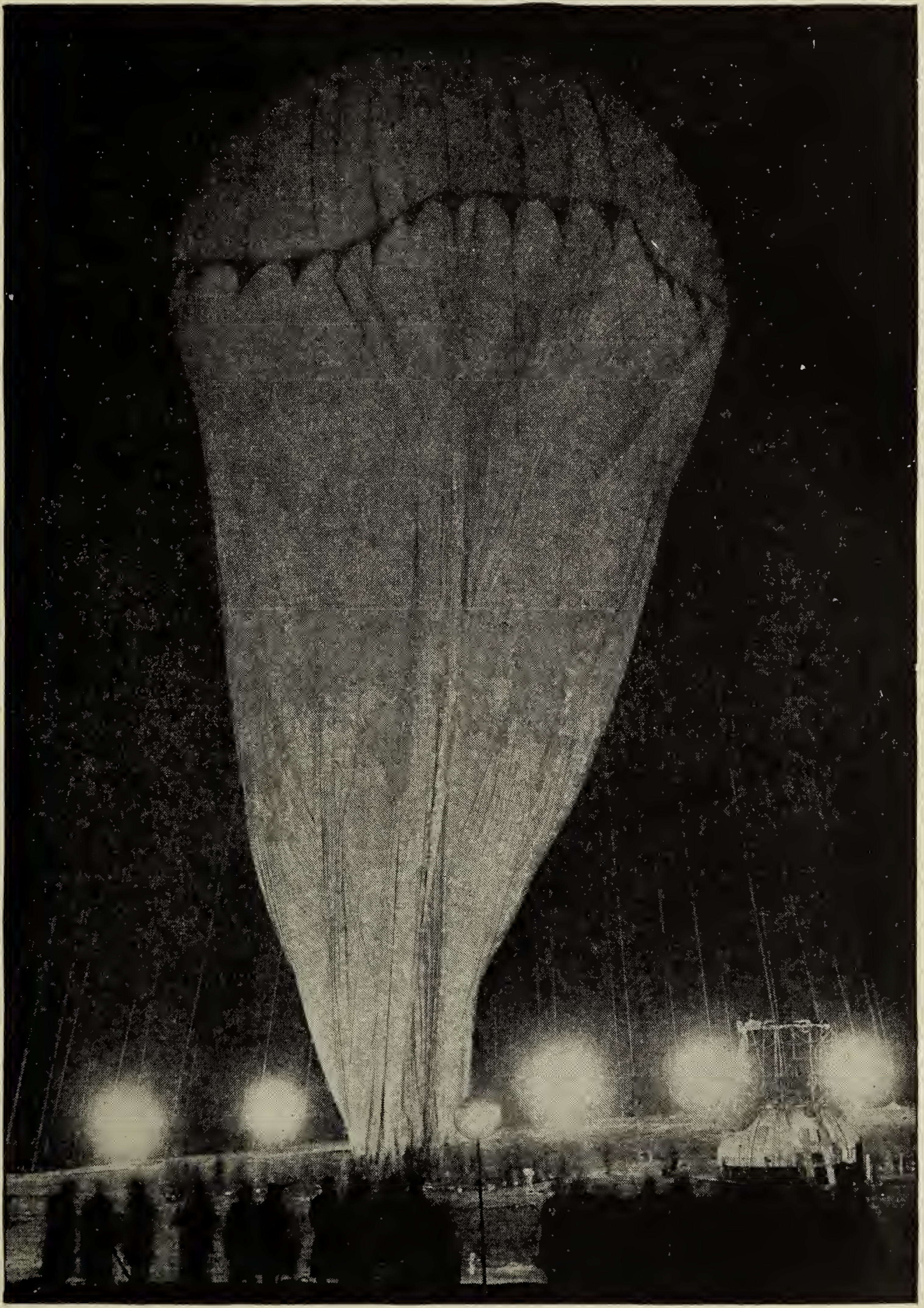
© White Star-Cunard, Ltd.

The Queen Mary

Top, showing small displacement when not loaded; bottom, note the greater displacement when loaded

flying at high elevations, must constantly take into consideration the altitude of their craft and the relative buoyancy of the atmosphere.

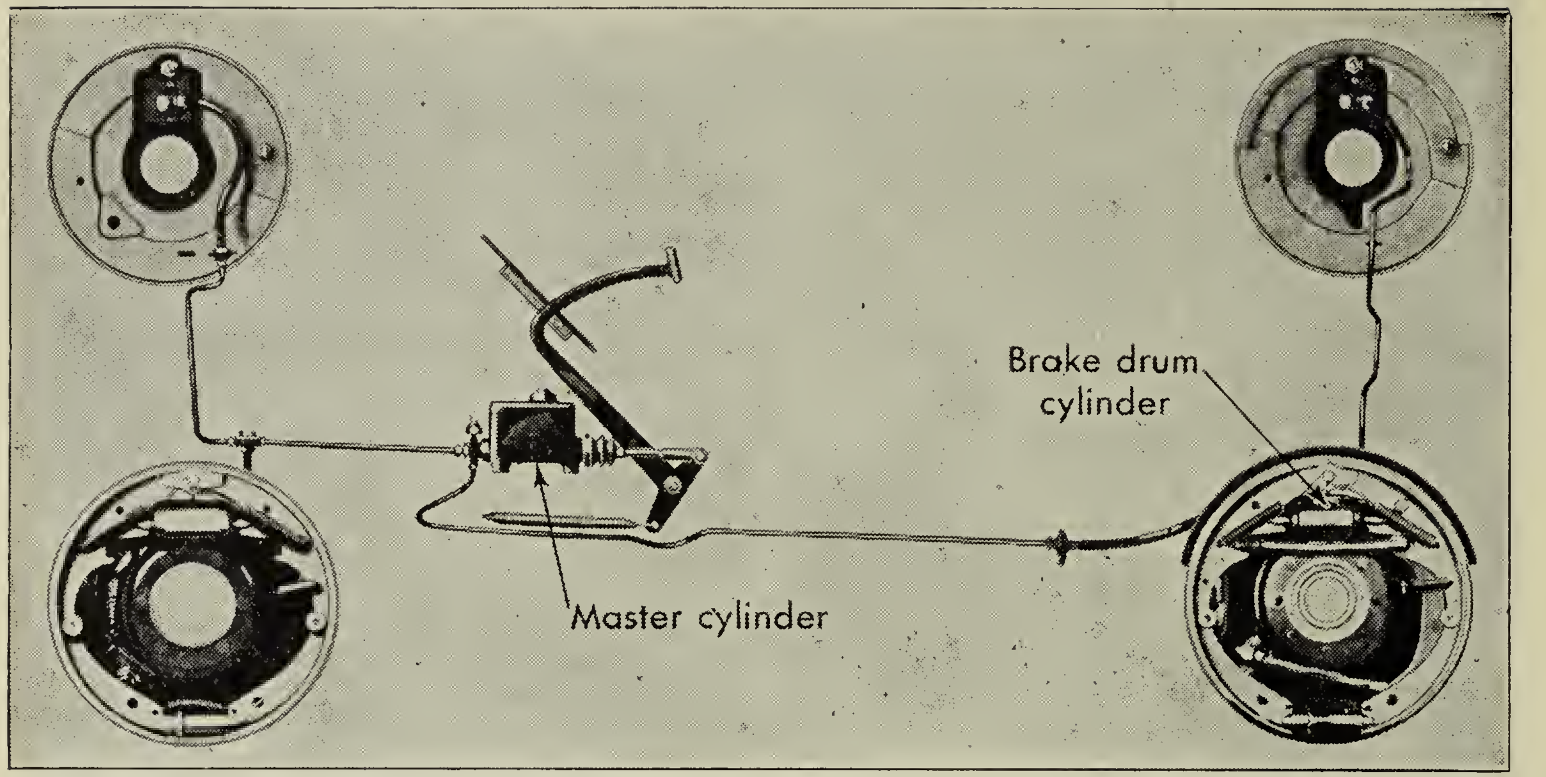
Fluids Possess Viscosity. We have found that fluids are so named because they tend to flow. They also offer resistance to flow, which is called *viscosity.* Perhaps the best explanation of viscosity is that it is caused by the friction between the molecules as they move among one another. If one should fill seven tall jars of equal height with ether, gasoline, water, paraffin oil, olive oil, glycerin, and very stiff pine pitch, respectively, and then should drop a small steel ball, such as a bicycle bearing, into each, very different results would be observed. If it should take a second for the ball to reach the bottom of the jar of water, it would take but a third of a second to drop through the ether and only a trifle longer to fall through the gasoline. It would reach the



Underwood & Underwood

Stratosphere balloon, the Explorer II, in process of inflation

The balloon is about ready for the attachment of the gondola, right foreground. Objects like this are supported by the buoyancy of the atmosphere



Bendix Products Corporation

Hydraulic brake system of a modern automobile

When the brake pedal is pushed, the fluid is forced from the master cylinder into the brake-drum cylinders, thus expanding the brake shoes

bottom of the paraffin oil in two and three-eighths seconds, that of the olive oil in eighty seconds, that of the glycerin in twelve and one-half minutes, and that of the pitch in about ten thousand years. Although the densities of these substances are not so greatly different, the viscosities are exceedingly dissimilar; and the differences in the action of the ball are due to the different viscosities.

Substances that have a high viscosity, such as glycerin or pitch, we speak of as being thick; those with a low viscosity, as ether or gasoline, we call thin. Viscosity may be measured by letting the substances flow through long, fine tubes at a known temperature. The longer it takes for, say, 10 cc to make the passage, the greater the viscosity.

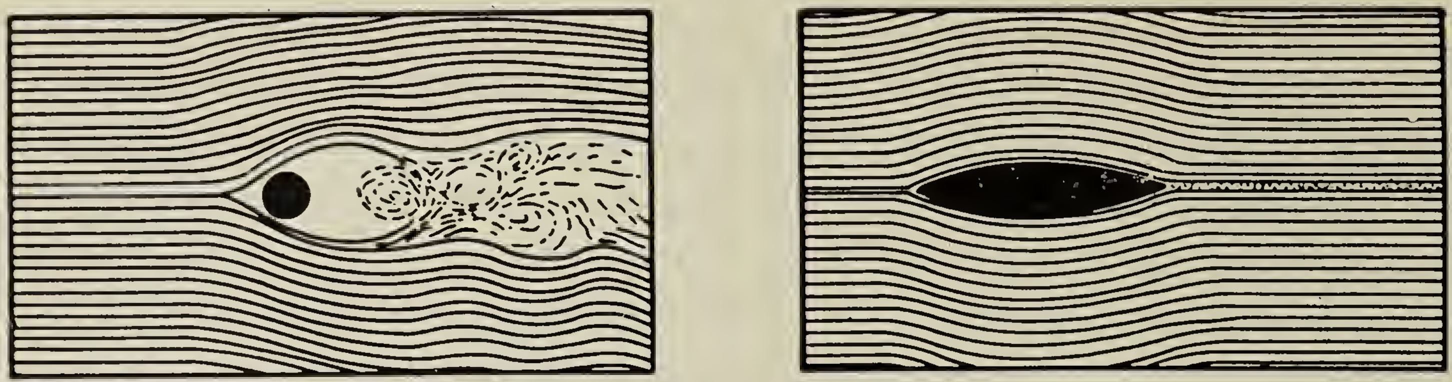
Viscosity is greatly affected by temperature. Heat, as we have found, tends to separate the molecules of a fluid farther, so that they flow past one another with less friction. Thus the degree of viscosity is reduced. Molasses, which will scarcely flow in January in northern climates, may be readily poured in July. Starch paste is much thinner when hot than when cold. In one observation six pints of boiling water leaked through a hole in a container in about the same time that one pint of ice water leaked through it. Highway workers always heat the asphalt to reduce the viscosity to such a degree that it may be poured into the cracks which they are repairing in the pavement. Wax candles bend in hot summer weather because their viscosity is reduced.

Viscosity is an important quality of lubricating oils. Machinery bearings, if oil were not used, would wear out quickly because of friction and heat. But the lubricants that are used form a thin film of molecules between the two wearing surfaces and thus, by slightly separating them, reduce the friction. Bearings of light machinery with little friction, such as a vacuum cleaner or a watch, require a light oil, which makes a thin film; those of heavy machinery, such as a tractor or an automobile, need a heavy grease to form a thick film.

Oils for the crankcases of automobiles are sold by numbers which indicate the degree of viscosity. The numbers are arranged on a scale determined by the Society of Automotive Engineers of America. No. 10 oil is a very light one, and No. 60 is an extremely heavy one. In moderate summer temperatures most automobiles in good mechanical condition should be lubricated with a medium-numbered oil. In very hot weather a heavier oil may be used, and in cold weather a lighter oil. Heavy oil, under ordinary conditions, should never be used in extremely cold weather. The high viscosity results in both difficulty of operation and loss of power. Moreover, heavy oil throws a great strain upon the starter in the winter time.

Fluids in Relation to Transportation. All fluids, largely because of viscosity, offer resistance to the passage of a solid body through them. In fact, engineers spend time and businessmen and other persons a great deal of money pushing ships through water and airplanes and motorcars through air.

The resistance to be overcome arises from more than one source. Whenever an airplane or automobile progresses rapidly through the air, the surrounding gaseous molecules rub vigorously against the surface of the moving object. This resistance is known as "skin friction." Its effect is similar to that of a brake. When ships plow through the water, the resistance relative to the speed is even greater. In this case it is all the more pronounced because the water sticks to, or wets, the surface of the vessel. In other words, the adhesive attraction between the surface molecules of the ship's hull and those of the water is greater than the cohesive attraction between the water molecules themselves. For this reason most of a ship's energy is spent tearing the molecules of water apart along its course. It has been estimated that 80 per cent of a ship's power is spent in this way. Shipbuilders, to avoid this loss, have tried to perfect a paint that water would not wet; but as yet they have not been successful. It has been said that if someone could develop a paint for a ship that would enable the ship to slip through the water with half the friction enountered at present, "he would make a stupendous fortune and win the American Cup."



More eddies are produced by a round object than by a spindle-shaped object

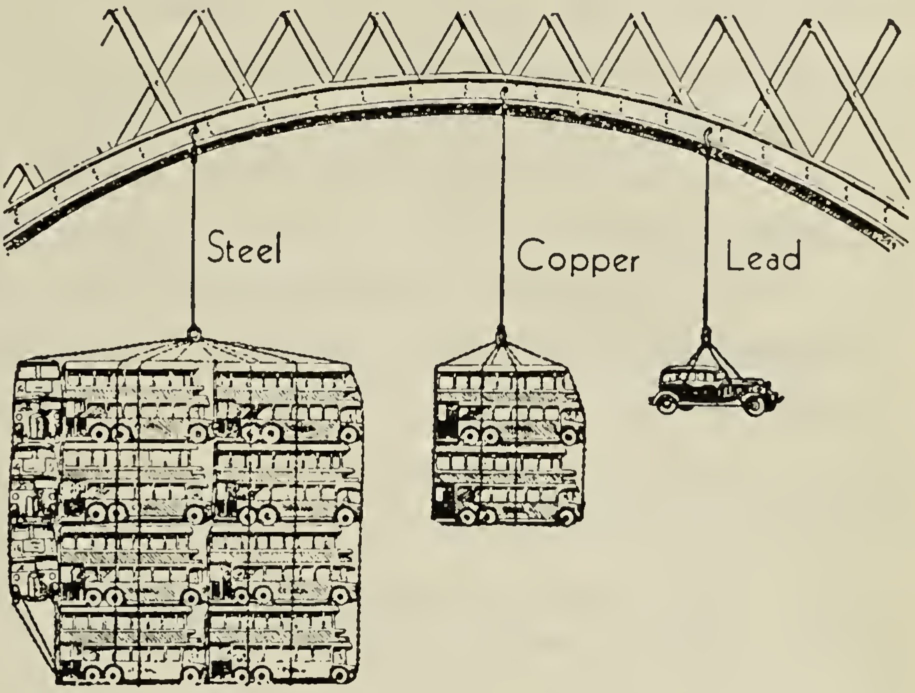
Another source of retarding influence is eddies in the air or water (see figure above). When water is forced through pipes rapidly, that in the center flows fastest, while that at the sides, because of friction, is retarded. The result is a series of whirling eddies in the pipe which greatly reduces the flow of water through it. A swollen stream shows the same phenomenon. Many such eddies have been observed to occur when a mountain stream was turned into a torrent by melting snows.

The resistance offered to boats, airplanes, and automobiles by the medium in which they are moving varies directly as the square of their velocities. For example, the air resistance exerted on an automobile running 40 miles an hour is almost twice as great as when the automobile is going 30 miles an hour. At a speed of 60 miles an hour, the resistance is four times as great as at 30 miles.

The expenditure of power is commensurately greater as velocity is increased. Tests have shown that if an automobile makes 21.7 miles on a gallon of gasoline at a speed of 40 miles per hour, it will make but 18.5 miles at a velocity of 60 miles. If the speed is raised to 80 miles, the mileage drops to 13.8 miles per gallon.

For this reason and to prevent eddies from being formed in the surrounding medium, construction engineers try in every way to reduce the resistance to the fluid flow past the surfaces of their craft. Since fluid resistance cannot be eliminated, the object is so to fashion the shape of the conveyance as to make the fluid medium slip past it with the least possible friction. In airplane construction the wings are so shaped as to give lifting power at the expense of drag. But this is a special case.

The attempt to promote fluid flow has led to streamlining. Streamlined automobiles, airplanes, and railway trains are coming in rapidly. Perhaps for conveyances that move over the ground, such as motorcars and railway trains, the economy of streamlining has been overstressed in the mind of the public. Zierer and Macauley, two engineers, recently took a passenger car from regular automobile stock and by adding sections completely streamlined it. They found that streamlining increased the fuel economy 56 per cent at a speed of 80 miles per hour; but when the speed was cut to 60 miles per hour, the fuel economy due to streamlining dropped to only 17 per cent. At ordinary speeds the fuel saving in automobiles is not more than 8 per cent, and in train construction, streamlining is one tenth science and nine tenths advertising. The great saving in the operation cost of streamlined motorcars and streamlined trains is due to weight reduction rather than to reduced air resistance. The use of light-metal alloys, such as aluminum and magnesium, has made this possible. In the case of airplanes, however, which may move at a speed of three or four miles a minute, streamlining is very important.



Solids have different tensile strengths

The relative weight supported by a rod of steel, copper, and lead 1 square inch in cross area[1]

The interest of aeronautical engineers and airway companies in the possibilities of airplane routes through the region of the stratosphere is partly due to the reduced resistance to be found there. Another inducement, of course, is its windless, cloudless condition. The stratosphere begins at a height of about seven miles. Its density is much less than that of the air near the ground. If successful flying at this elevation could be achieved, the saving in power would be great.

Solids Have a Compact Molecular Arrangement. We have found that under ordinary conditions a gas has neither a fixed volume nor a fixed shape, and that a liquid has a fixed volume but not a fixed shape. A solid, however, roughly speaking, has both. Increased temperature may make a solid expand slightly, as we shall see in the next chapter; but for practical purposes we may regard a solid as being fixed as to both volume and shape. Solids are the most compact form of matter. In them the molecules have been brought into such an intimate relation that they do not travel from place to place, as in gases and liquids. They are in a constant state of oscillation, however, within their positions.

[1] From *The World of Science*, by F. S. Taylor. By permission of Reynal & Hitchcock, Inc., and William Heinemann, Ltd.

Moreover, in solids the molecules are more or less tightly held together by the force of cohesion. When matter is in this state, the attractive force existing between the molecules is, in some instances, astonishing. In a rod of rivet iron, one square inch in cross section, the cohesion is so great that it requires a force of twenty-five tons to pull it apart (see figure on page 189). In other words, it could sustain the weight of more than three hundred 150-pound men without being pulled in two. Yet, close together as the particles are when in this state, there is relatively much space between them.

Some Solids Sublimate. One finds a tremendous cohesive force in a crystal of rock salt, for example. The crystalline structure cannot be broken down and the molecules released without the application of a great deal of energy. Such is not the case with a substance like gum camphor. On one occasion a rather large lump of gum camphor was set aside in an open, widemouthed bottle. Some months later the gum camphor had disappeared altogether. The kinetic energy of the molecules was sufficient to overcome their weak cohesive force, and the molecules had drifted out as individual particles. If these particles could have been captured and enclosed, they would have redeposited themselves again as a solid on the sides of the container. This phenomenon is called *sublimation* and affects our life in many ways. Iodine crystals act in the same way. Sulfur, when heated moderately, will sublimate and become deposited on the sides of the container as a powder, or "flowers of sulfur." Wet clothes in subzero weather will "freeze dry" because the ice crystals gradually sublimate.

Questions for Study

1. How are the activities of man conditioned by the different states of matter which form a part of his environment?
2. How may a substance be changed from one state of matter to another by changing the amount of kinetic energy possessed by its molecules?
3. Contrast the spatial relationships believed to exist between the molecules in the different states of matter.
4. Can you think of any examples in your everyday experience of the functioning of Boyle's law?
5. Upon what characteristic of gases does the transmission of floral perfumes depend?
6. Upon what characteristics of fluids does the flow of water in your home water system depend?
7. How may the principle of buoyancy be explained?
8. How does the principle of buoyancy enter into the problems of transportation?

9. Most filling stations carry types of automobile oils rated as 10, 20, 30, and so on up, by steps of 10, to about 70 S.A.E. (Society of Automotive Engineers). How do these grades of oils differ in quality, and for what type and condition of car should each be used?

10. It has been said that at a speed of 80 miles per hour 75 per cent of an automobile's horsepower is consumed in overcoming air resistance. What principles and properties of gases are involved as causes?

11. How does the principle involved in Charles's law affect your daily experience?

12. Why does adding soap to water cause it to form bubbles more readily?

13. Why will hot water form suds more readily than cold water?

14. Why do fresh vegetables, such as Lima beans and peas, boil over readily when being cooked?

15. Why will puncturing the tin screw cap of a vacuum-packed jar of pickles make it possible to remove the cap easily?

16. Why does the streamlining of ships, automobiles, and airplanes tend to reduce the cost of operation?

17. In greenhouses certain fungous diseases may be combated by placing a piece of sulfur on a hot steam pipe and leaving it there. Explain the physical principle involved.

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CHAPTER THIRTEEN

The New Concept of Matter Explains Many Aspects of Chemical Behavior

Chemical Changes Alter the Composition of Substances. A mixture of sulfur and molasses used to be a very popular spring medicine. In this mixture there was no interaction at all between the sulfur and the molasses, not even a physical one to form a solution. The granular sulfur was simply suspended in the heavy molasses. By the addition of a generous supply of water the molasses might be dissolved out, while the sulfur, insoluble in water, would settle to the bottom of the container. By filtration the sulfur might be completely separated and then be reduced to a solution, too, by being dissolved in carbon disulfide. Then by evaporation both the sulfur and the molasses might be recovered from their respective solutions intact. All these transformations were purely physical. They affected molecular relation and arrangement, but not molecular composition or structure.

On the other hand, if one had applied a suitable degree of heat to the sulfur and molasses mixture, an entirely different result would have followed. Uniting with the oxygen of the air the molasses would have been oxidized to carbon dioxide and water vapor, and the sulfur to sulfur dioxide. Here the sulfur and molasses, as such, would have been completely destroyed. Their molecules would have been disrupted, and their constituent atoms would have combined with oxygen to form entirely different compounds. Such is the distinction between physical and chemical changes in matter.

At this juncture we wish to disregard physical changes and center our attention upon chemical reactions alone. There is scarcely a fundamental change we can think of in the universe that does not involve them. They are abundant on every hand. If they were audible, the world would be buzzing with the sound of these chemical reactions all the time. Out in the fields, where soil-fertility changes are going on; on the faces of exposed rocks, where oxidations are taking place; in factories, where articles of commerce are being manufactured; in plants, where food is being made; and in the bodies of animals as well, whole trains of chemical transformations are following one another in orderly fashion. In man's body, from the cradle to the grave, the whole range of his physiological changes is chiefly a continuous series of complex and intricate chemical reactions.

Chemical Compounds Are Composed of Chemical Elements. Substances such as iron, oxygen, and zinc, which are composed of but one kind of atom, are known as chemical elements. We have learned that there are ninety-two elements. Substances that are composed of two or more elements chemically combined are called chemical compounds. Some compounds are simple, being composed of but two elements. Water and table salt are examples, and the chemist expresses them by the simple formulas H_2O and $NaCl$. On the other hand, compounds of almost any degree of complexity imaginable may be produced. Their possible number runs into the hundreds of thousands. In fact, there seems to be no practical limit to the number of compounds that may form or be formed. The formula for one of the soaps is $C_{17}H_{35}COONa$, which gives but a faint idea of how complicated chemical compounds may become.

Scientists Use Symbols and Formulas to Indicate Chemical Changes. We have all marveled at the rapidity with which a stenographer can take dictation. A few marks resembling hieroglyphics on her pad record a whole paragraph of ideas. Strangest of all, she can, even after many days have elapsed, transcribe this curious train of marks and signs back again into clear language.

The chemist too has a system of shorthand. He abbreviates. He uses but a one-letter or a two-letter symbol to express the name of an element. Jakob Berzelius, a great Swedish chemist who died about the time that the California gold rush was dotting the Great Plains with dusty trains of plodding emigrants, was perhaps more responsible for this system of chemical shorthand than any other man. Its general adoption has saved untold hours of time for both student and research worker. In the chemist's language Mo means molybdenum, and Pr stands for the long name of the element praseodymium. But the chemist carries his abbreviated system farther. He combines these symbols of elements to indicate formulas for chemical compounds. For instance, when he writes H_2SO_4, he not only says "sulfuric acid" but shows that two atoms of hydrogen, one of sulfur, and four of oxygen enter into the molecular composition of this compound.

Indeed, the chemist carries his "chemical shorthand" even farther. By the use of symbols and formulas in a "chemical equation" he can express a whole series of chemical processes and indicate the products which result from it. If he wrote out in full the whole chemical story indicated, it might require half a page to do it. Take the following equation, for example:

$$2\,HCl + CaCO_3 \longrightarrow CaCl_2 + CO_2 + H_2O$$

By this equation we are told that hydrochloric acid (HCl) and calcium carbonate ($CaCO_3$) interact to produce calcium chloride ($CaCl_2$), carbon dioxide

(CO_2), and water (H_2O), and that two molecules of the acid react with one molecule of the carbonate. The numerical coefficient in each case indicates the necessary number of molecules involved, and the subscript indicates the number of atoms of that particular element in the molecule under consideration. When no subscript is given, 1 is understood.

We have found that there are approximately ninety known elements and that each has its symbol. We have learned further that there are thousands of compounds known to science, and doubtless thousands of others still unknown. All the average reader can expect to do, then, is to understand the principles involved and to learn some of the commoner reactions that affect his everyday life.

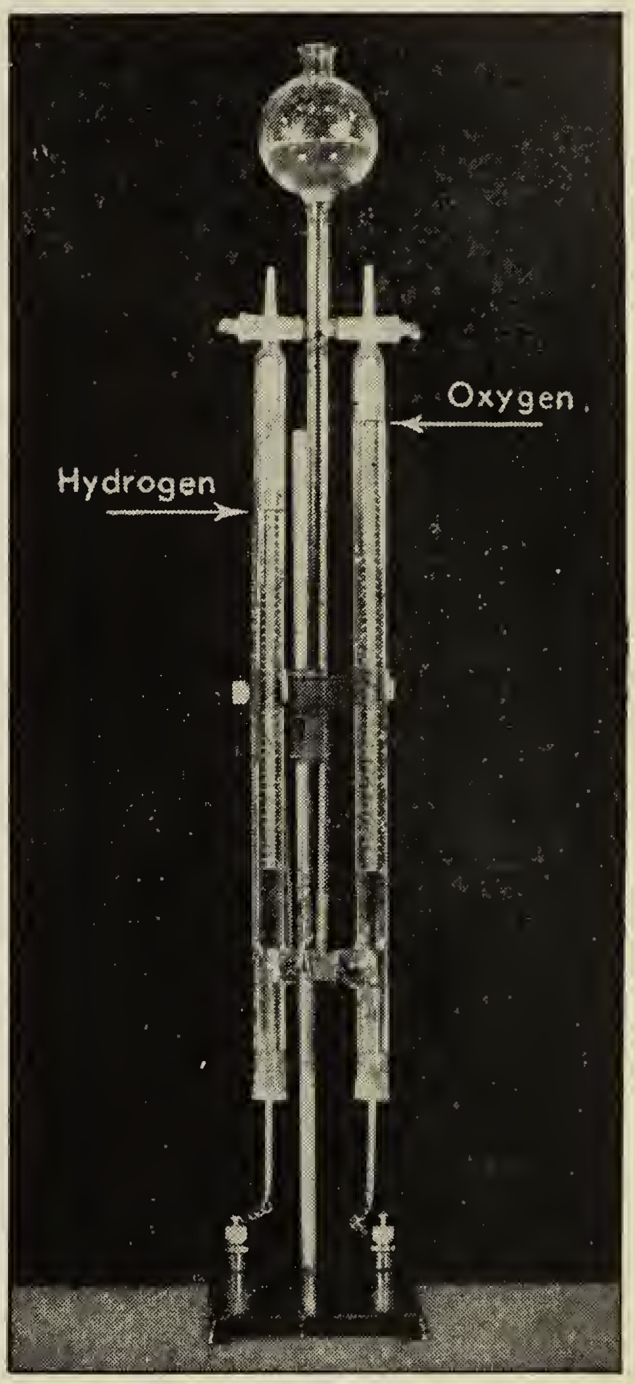
The Atoms of Compounds Are Held Together by an Electrical Attraction. The ancient Greeks had an ingenious theory as to why atoms combined to form chemical compounds. The reader will remember that it was they who first assumed the existence of atoms. The Greeks reasoned that some atomic surfaces must be covered with tiny hooks. These hooks must interlock, somewhat after the manner of matted burs, to form molecules. Thus were formed the hard, durable substances. Other atoms were thought to have smooth, hard surfaces, so that they did not cling together but slipped past one another easily. Of such atoms gases and liquids were made. Thus the whole range of chemical substances was built up.

As man's knowledge increased, these childlike ideas gave place to more rational ones. Later, chemists said that atoms were held together in compounds by "bonds" due to a force called "chemical affinity." This term, as is perfectly evident, gave no hint as to the nature of the combining force. A scientist working far out at the fringe of human knowledge often has to set up a hypothesis as a tentative explanation. He does so, however, with a mental reservation, knowing that subsequently discovered facts may make it necessary to modify his hypothesis.

While studying chemical affinity, scientists recognized that chemical elements must manifest different degrees of this force. For example, the sodium atom (Na) has the power to hold one atom of chlorine (Cl) in combination, forming common table salt, expressed by the chemist as NaCl. Calcium (Ca), on the other hand, has double the combining power of sodium and can hold two atoms of chlorine in combination, forming calcium chloride, or $CaCl_2$. This variation in the power of different elements to combine with other elements came to be known as *valence*, from the Latin *valentia*, meaning "strength."

Chemists, however, continued to work on chemical affinity. In 1800 Nicholson and Carlisle, two Englishmen, decomposed water with an electric current. Since it was possible to decompose water into its constituent parts, hydrogen and oxygen, Sir Humphry Davy, taking his cue from Nicholson and Carlisle, speculated as to the possibility of breaking down other compounds. So, dissolving some caustic potash (potassium hydroxide) in a platinum spoon, he sent the current from an electric battery through the solution. To his astonishment globules of the mercury-like substance began to collect on the negative electrode. He had decomposed potash, and he named the metallic substance which he had obtained potassium.

It had also been found that when water is decomposed by an electric current, the hydrogen atoms all go to the negative pole, and the oxygen atoms to the positive pole. Moreover, the volume of the hydrogen is just twice that of the oxygen. Here was a flash of light, penetrating the heretofore unilluminated question as to the nature of chemical affinity. If in water the hydrogen atoms bear positive charges and the oxygen atoms negative ones, would not these opposite charges attract each other and in this way hold the atoms together in the molecule? The nature of chemical affinity now seemed clearly to be electrical.



Water may be decomposed into hydrogen and oxygen by means of an electric current

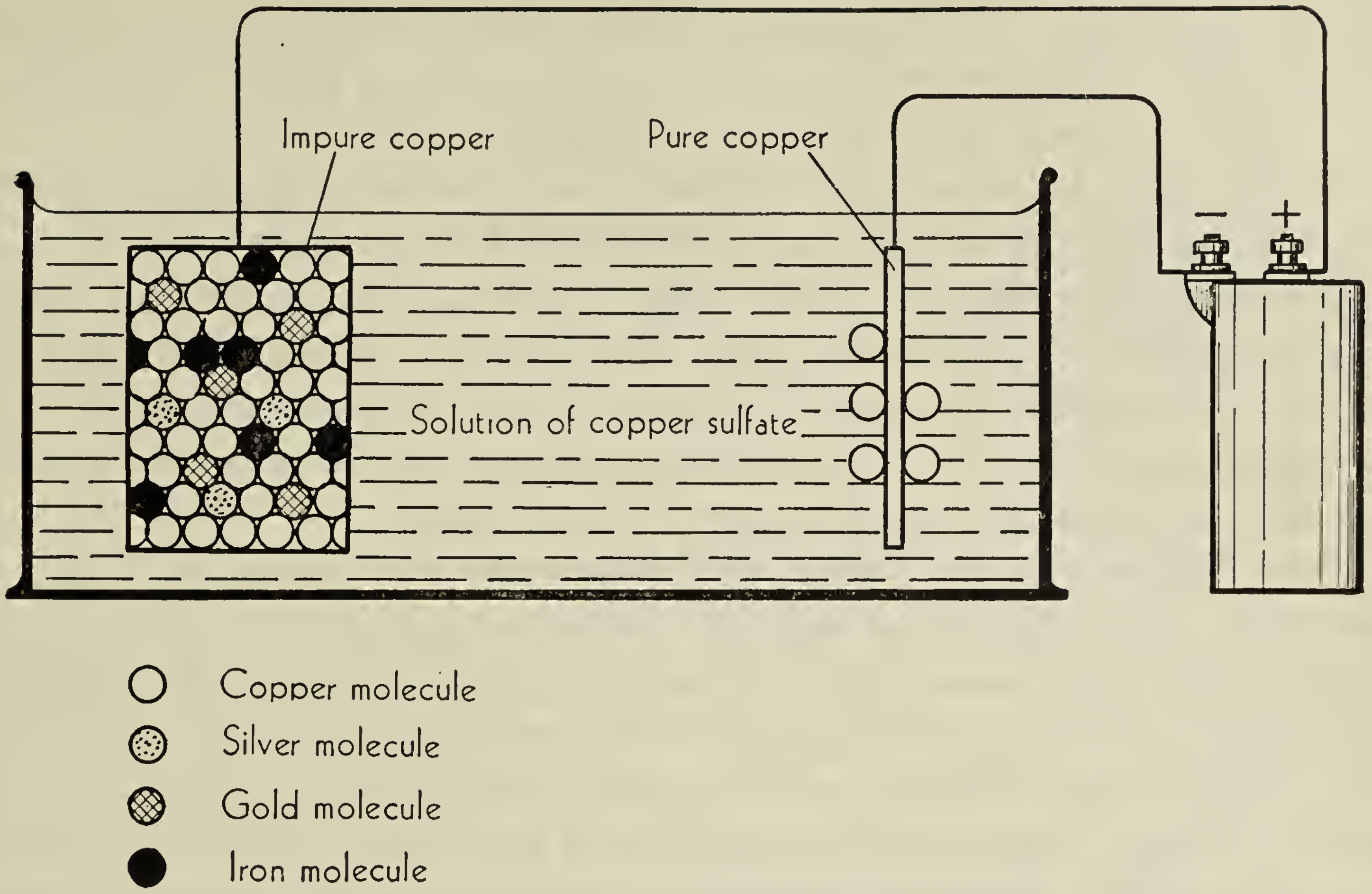
Arrhenius Explained Electrical Decomposition by the Theory of Dissociation. The Swedish chemist Svante Arrhenius, in 1887, advanced a theory to explain how the electrical force develops which holds atoms together in compounds. His ideas in modified form are now generally accepted by chemists. He believed that in solution many substances *dissociate*, forming ions (electrically charged particles); that is, the molecule breaks into two or more parts, instead of remaining intact, as was formerly supposed. One of the ions may consist of a single charged particle; the other may consist of another atom or a group of atoms called a *radical*, which acts chemically like a single ion.

According to the theory of dissociation, the ions of a compound carry opposite electric charges. For instance, when a molecule of sodium chloride is dissociated, the sodium ion always carries a positive charge and is designated Na^+; the chlorine ion, on the contrary, carries a negative charge, which is indicated by the symbol Cl^-. When a molecule of nitric acid (HNO_3) dissociates, the ions formed are indicated as H^+ and $(NO_3)^-$.

This theory, moreover, furnishes an acceptable explanation of *electrolytes.* Electrolytes, when in solution, exist at least partially as charged particles and will conduct a current through the medium in which they are dissolved. Let us use an electric cell as an illustration. If it is set up in such a way that the electrodes are connected with each other through a salt solution, and the circuit is closed, the random diffusing ions in the vicinity of the electrodes are influenced by the charges which the electrodes carry. The negative ions are attracted to the positive pole and the positive ions to the negative pole. Other ions diffuse in to take the place of those just pulled in by the electrodes. These ions, in turn, fall under the influence of their respective poles, and thus a current continues to flow. These random-diffusing, dissociated charged particles, which are attracted by oppositely charged poles, are called *ions* from a Greek word which means "going." When the ions arrive at their respective poles, their electric charges become neutralized, and they thus become neutral atoms of hydrogen, copper, silver, and so on, depending on the kind of solution used. Dissociation is now most commonly referred to as *ionization.* Ionization is a very important phenomenon in chemistry and is involved in many chemical reactions that take place in solution.

After the discovery of X rays, it was found that many substances do not have the atoms combined into definitely formed molecules, as had been assumed. For instance, when crystals of certain substances, such as common table salt, were X-rayed, the result showed that the component atoms were not securely locked together to form molecules. Instead the analysis revealed that the atoms are probably in as completely ionized a condition in the solid as they are in solution. From this it was inferred that the ionized condition of the atoms in the solid was maintained by a system of balanced charges, each ion exerting a minute electrical pull for the many ions of opposite charge that surround it.

When the atoms are dissolved in water, the ionized condition continues; but the attraction is less effective because the component particles of the solid are now separated by the intervening water molecules, which are conceived to act as a sort of electrical insulation. This permits the particles to travel more readily under the influence of an electric current. Indeed, by this theory all strong electrolytes in the solid state are conceived to have their ions associated



Copper may be deposited from a mixture of metals by electrolysis

by mutual electrical attraction and not to be definitely bound together to form molecules, as was formerly supposed. In the weaker electrolytes, such as acetic acid, it is necessary to assume a condition in which both ions and molecules exist. In the nonelectrolytes, such as cane sugar, a condition of complete molecular combination is assumed.

Electroplating Depends on the Principle of Dissociation. Before pursuing the main thread of our thought farther, it will be of interest to digress momentarily to consider electroplating, one of the practical applications of electrical dissociation. By this process articles such as the less expensive pieces of jewelry, cutlery, utensils, automobile trimmings, and scores of other objects are overlaid by a surface coating of some desired metal or metallic alloy. Finger rings and other jewelry that resemble gold may also be merely gold-plated. Automobile manufacturers, to keep their car trimmings bright and attractive and untarnished by atmospheric action, electroplate them with chromium. Other metals, such as copper, nickel, zinc, and tin, may be electrodeposited.

Essentially the process of electroplating resembles that of electrolysis. The object to be electroplated is used as a cathode. The opposite pole, or anode, may be of the same metal or of a different conducting substance. The two are then immersed in a bath consisting of a solution of a salt of the metal to be used as a plating. Since the liquid is a good conductor, the current used is one of low voltage. As the process continues, the metal from the decomposed metallic salt is deposited on the cathode, or object being plated. It is obvious that the plating may be of almost any thickness desired.

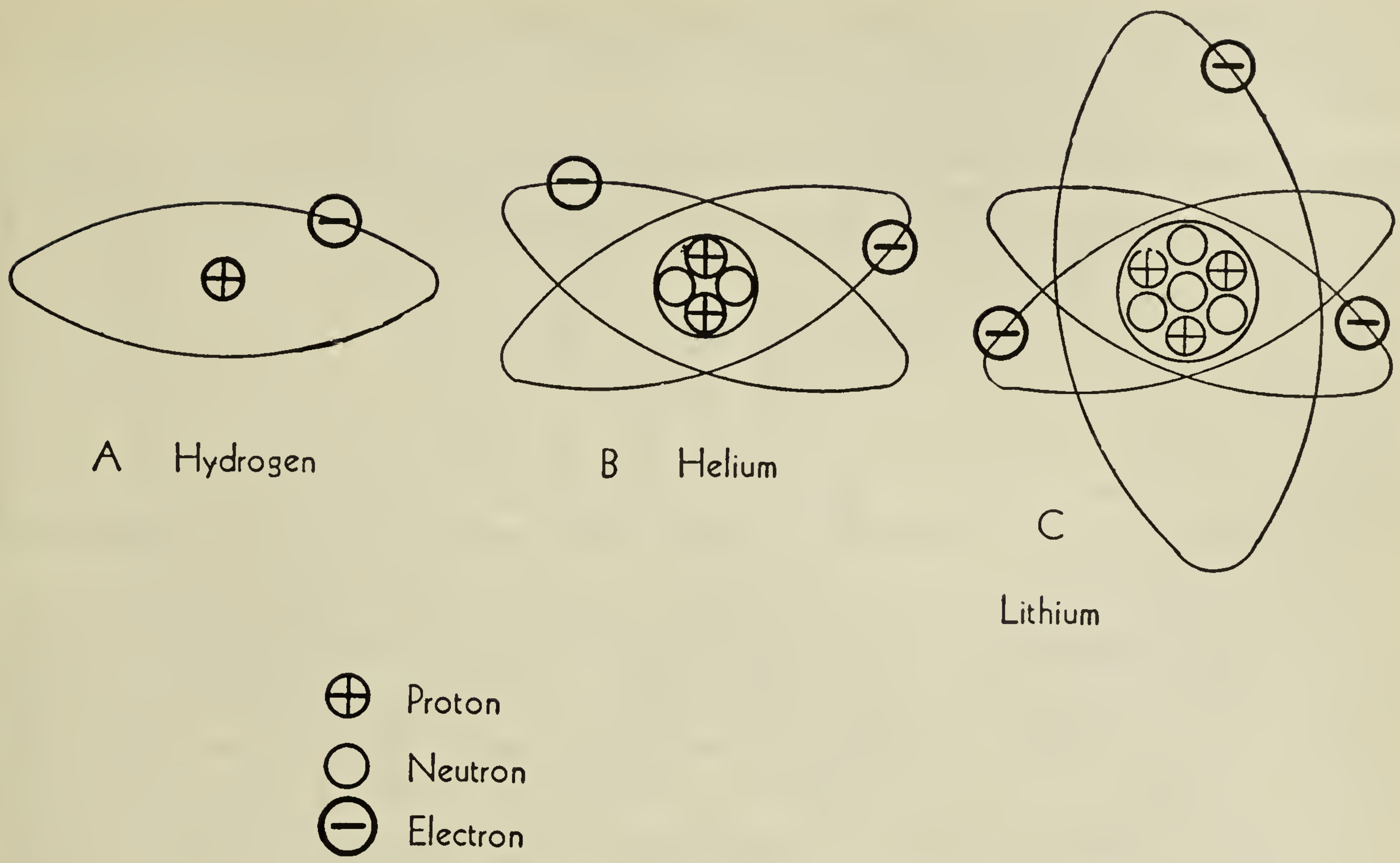
Metals may be refined by applying the principle of electrolysis. For example, an ingot of impure copper from which the refined metal is to be separated is connected to the positive electrode and a thin plate of pure copper to the negative pole of the apparatus. Both hang in a copper sulfate solution. As the current passes, the impure copper in the ingot is dissolved, and the pure metallic copper from the solution deposits on the original copper plate. Aluminum also is separated by the process of electrolysis.

The Electrons in the Outer Shell Determine the Combining Force of the Atom. The evidence furnished by electrolysis indicated that atoms unite to form molecules because they are bound together by electrical attraction. But there were other perplexing aspects of this whole problem still unanswered. For instance, some elements, such as sodium and potassium, carried but one positive charge; others, such as barium and zinc, two; still others, such as aluminum, three. Moreover, there were elements bearing negative charges.

On the other hand, there were still other elements that were variable and might carry, under different conditions, two, three, or even five charges, as in the case of nitrogen, for example. How could this strange situation exist? What made the valence change in this way?

This whole question was an exceedingly baffling matter until the new conception of the structure of the atom was advanced. This led to a complete revision of our ideas concerning the fundamental nature of valence.

It will be remembered that when the atoms of different elements are built up, beginning with hydrogen, an increasing number of protons and neutrons seem to be combined to form the nucleus. Moreover, since the atom is a balanced electrical system, the number of protons within the nucleus is equaled by the number of electrons outside. Thus hydrogen (atomic weight, 1; atomic number, 1) has one proton in its nucleus and one electron outside. Sodium (atomic weight, 23; atomic number, 11) has eleven protons associated with twelve neutrons to form its atomic nucleus, and has eleven electrons in the outer orbits to balance the positive nuclear charges. Suppose that a hydrogen atom meets another atom of some kind that pulls its single outside electron off. Now, since the proton alone is left, the resulting H^+ ion possesses one positive electric charge, or has a positive valence of 1. On the other hand, the other atom, which captured the electron from the hydrogen atom, has increased its outer electrons by one and has taken on a negative charge. This gives it a negative valence of 1.



Schematic diagram to illustrate atomic structure

Helium, next to hydrogen in the atomic table, has two electrons in its outer orbit to balance the positive charges of the two protons in the nucleus. Helium, with a few other gaseous elements, under ordinary conditions will not give up through chemical changes a single outside electron to acquire a positive charge; neither will it capture an electron from another kind of atom to take on a negative charge. Hence, like people who refuse to associate with their fellows, the helium atoms "go it alone" in the chemical world. Because of this characteristic the atom is said to have a valence of zero and to be an inert substance. It is for this reason that helium is such a safe gas for inflating dirigible balloons.

Lithium, the third element in the atomic table, has three electrons to balance the three positive charges on its nucleus. The electrons in the atoms of these three elements (hydrogen, helium, and lithium) are shown in the accompanying diagram. It will be seen that the electrons tend to arrange themselves in successive shells about the nucleus. Moreover, and this is a very important principle, *it is the outer shell alone that seems to affect valence* and thus determine the combining or chemical properties of the elements.

The fourth element, beryllium, has two electrons in the second shell. The number of electrons in this shell is increased by one for each succeeding element up to neon, whose outer shell contains eight. In neon we again have an inert element like helium.

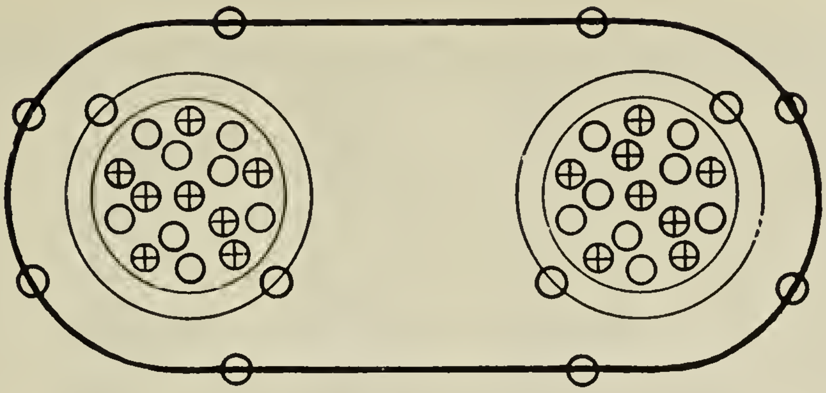
The following table shows the shells and the number of electrons believed to be in each shell for a few elements:

	K	L	M	N	O	P	Q
Helium	2						
Neon	2	8					
Argon	2	8	8				
Krypton	2	8	18	8			
Xenon	2	8	18	18	8		
Radon	2	8	18	32	18	8	
Uranium	2	8	18	32	18	12	2

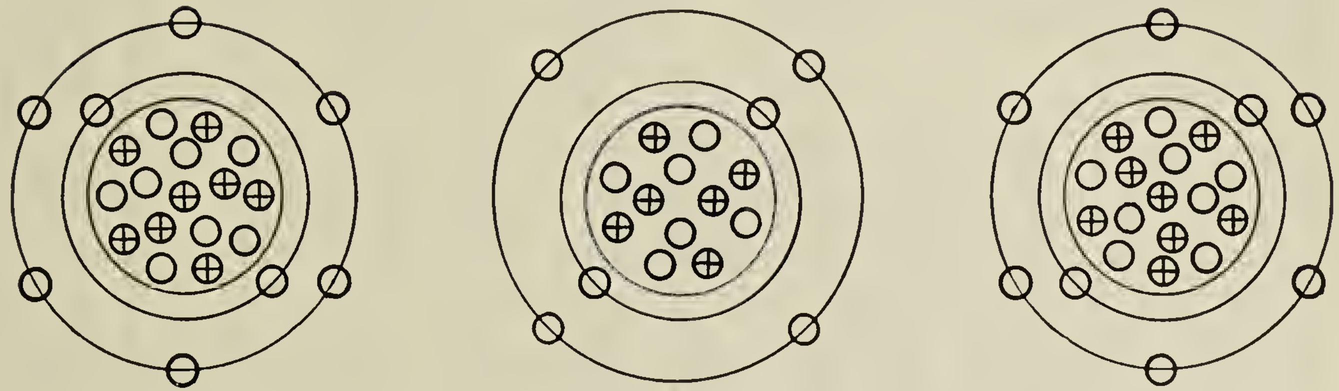
The outer, chemically active valence shell never exceeds eight electrons. It may, when incomplete, consist of a smaller number but never of more than eight. Electrons may be condensed within the inner shells, however, to the number of eighteen or even thirty-two. Moreover, it appears that the atoms of elements, where electrons are concerned, are like people with their money. Some are liberal spenders, while others are grasping. Sodium, for example, gives up the single electron in its outer shell readily, becoming a positive ion with a valence of 1 as a consequence.

If one heats sodium in chlorine gas, it burns vigorously. The sodium alone readily gives up the one loosely held electron in its outer shell, thereby becoming a positively charged ion; the chlorine atom, which has seven electrons in its outer shell, takes on with apparent avidity this unattached electron and in so doing becomes a negatively charged ion. Now the two readily become associated to form table salt (NaCl). Nitrogen is a veritable spendthrift and may part with two, three, or even five electrons from the outer shell. Oxygen, on the other hand, does not give up its own electrons, but will take them from other atoms, thereby acquiring a negative valence of two. These ions with opposite charges, then, will readily combine to form compounds. Valence of this kind is called *electrovalence.*

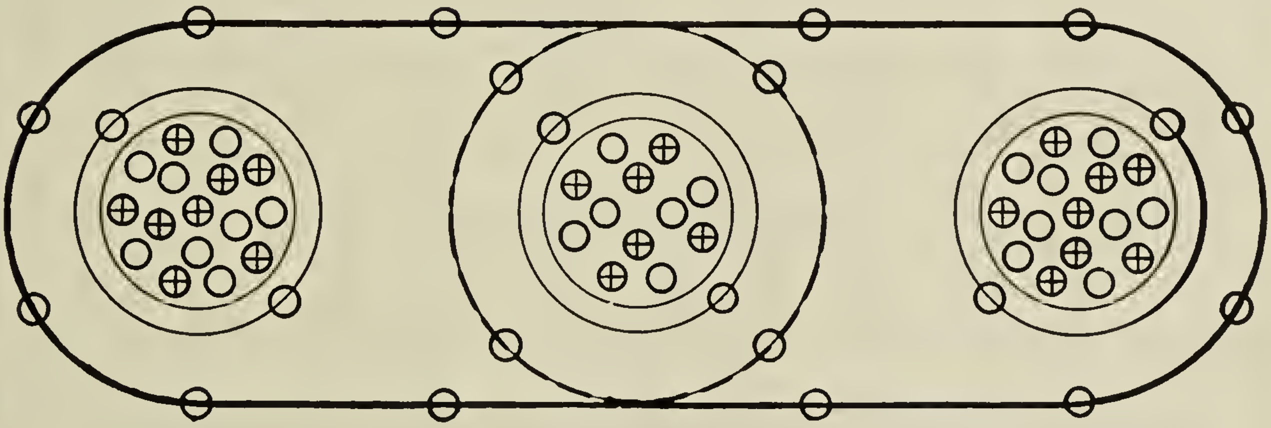
Sometimes, it is believed, molecules of a complex substance are built up by atoms sharing the same electrons. Let us take, for example, the gases hydrogen and oxygen. The atoms of these gases, under usual conditions, do not exist alone for any length of time. Instead two of the hydrogen or two of the oxygen atoms combine to form a molecule either of hydrogen or of oxygen. Here we have the phenomenon of two of the same kind of atoms combining to make a molecule, instead of two with unlike charges. How can this be, since two atoms of the same element in their normal condition must carry the same complement of electrons in their outer shells?



Oxygen molecule



Oxygen atom Carbon atom Oxygen atom



Oxygen atom Carbon atom Oxygen atom

Schematic diagram showing covalence

To explain this combination, it is necessary to assume the sharing of electrons by the two atomic nuclei. Under such conditions there are usually two atoms of the gas in the molecule. If no free electrons are present with which the atoms may combine, then two of the same kind of atoms are conceived to go together by sharing electrons with each other. In such cases it is believed that one or more shared electrons are held by each atomic nucleus. This condition is known as *covalence.*

Such a combination is very stable, and the strength of this union is shown by the fact that to secure atomic hydrogen, for instance, very vigorous treatment must be applied—such treatment as that of the electric arc, whose temperature is so high that it represents great quantities of energy.

THE PERIODIC ARRANGEMENT OF THE ELEMENTS AND THE ATOMIC NUMBERS[1]

Type of Hydride		RH	RH_2	RH_3	RH_4	RH_3	RH_2	RH			
Type of Oxide		R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4		
SERIES	GROUP 0	GROUP I	GROUP II	GROUP III	GROUP IV	GROUP V	GROUP VI	GROUP VII	GROUP VIII		
1	2 Helium He = 4.003	3 Lithium Li = 6.940	4 Beryllium Be = 9.02	5 Boron B = 10.82	6 Carbon C = 12.010	7 Nitrogen N = 14.008	8 Oxygen O = 16.000	9 Fluorine F = 19.00			
2	10 Neon Ne = 20.183	11 Sodium Na = 22.997	12 Magnesium Mg = 24.32	13 Aluminum Al = 26.97	14 Silicon Si = 28.06	15 Phosphorus P = 30.98	16 Sulfur S = 32.06	17 Chlorine Cl = 35.457			
3	18 Argon A = 39.944	19 Potassium K = 39.096	20 Calcium Ca = 40.08	21 Scandium Sc = 45.10	22 Titanium Ti = 47.90	23 Vanadium V = 50.95	24 Chromium Cr = 52.01	25 Manganese Mn = 54.93	26 Iron Fe = 55.85	27 Cobalt Co = 58.94	28 Nickel Ni = 58.69
4		29 Copper Cu = 63.57	30 Zinc Zn = 65.38	31 Gallium Ga = 69.72	32 Germanium Ge = 72.60	33 Arsenic As = 74.91	34 Selenium Se = 78.96	35 Bromine Br = 79.916			
5	36 Krypton Kr = 83.7	37 Rubidium Rb = 85.48	38 Strontium Sr = 87.63	39 Yttrium Y = 88.92	40 Zirconium Zr = 91.22	41 Columbium Cb = 92.91	42 Molybdenum Mo = 95.95	43 Masurium Ma = ?	44 Ruthenium Ru = 101.7	45 Rhodium Rh = 102.91	46 Palladium Pd = 106.7
6		47 Silver Ag = 107.88	48 Cadmium Cd = 112.41	49 Indium In = 114.76	50 Tin Sn = 118.70	51 Antimony Sb = 121.76	52 Tellurium Te = 127.61	53 Iodine I = 126.92			
7	54 Xenon Xe = 131.3	55 Cesium Cs = 132.91	56 Barium Ba = 137.36	57 Lanthanum La = 138.92[2]	72 Hafnium Hf = 178.6	73 Tantalum Ta = 180.88	74 Tungsten W = 183.92	75 Rhenium Re = 186.31	76 Osmium Os = 190.2	77 Iridium Ir = 193.1	78 Platinum Pt = 195.23
8		79 Gold Au = 197.2	80 Mercury Hg = 200.61	81 Thallium Tl = 204.39	82 Lead Pb = 207.21	83 Bismuth Bi = 209.00	84 Polonium Po = ?	85 Alabamine Ab = ?			
9	86 Radon Rn = 222.	87 Virginium Vi = ?	88 Radium Ra = 226.05	89 Actinium Ac = ?	90 Thorium Th = 232.12	91 Protoactinium Pa = 231.	92 Uranium U = 238.07				

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[1] Adapted from McPherson and Henderson's *Elementary Study of Chemistry: Introductory College Course* (Ginn and Company).

[2] Following lanthanum occurs a series of fourteen elements of atomic numbers 58–71. They closely resemble lanthanum and so cannot be distributed among the several groups. These elements, together with lanthanum, are known as the rare-earth elements.

The Chemical and Physical Properties of Atoms Make Possible the Periodic Table. Relationship in the atomic behavior of certain groups of elements had been noted as early as 1829. However, progress in recognizing this relationship was slow. Almost half a century later, 1869, Mendeléeff, a famous Russian chemist, prepared a table to show this rather striking periodic relationship. It was based on the atomic weights of the elements. To use Mendeléeff's own words, "The properties of the elements, both physical and chemical, vary as periodic functions of their atomic weights." This table has been greatly modified and improved since the death of Mendeléeff. In a somewhat simplified form it is shown on page 202.

The relationships expressed in this table are so many and so striking that it has become a regular part of the stock in trade of all chemists. In fact, the periodic table is to the chemical worker what logarithmic tables are to mathematicians. Nowhere has its dependability been more clearly shown than in the prediction of new elements which were not yet known when the table was formed. Since that time most, if not all, of the new elements have been discovered, and each in turn was found to fit into a blank space in the table, just like the missing parts of a jigsaw puzzle.

Questions for Study

1. Give examples of physical and chemical changes that have entered your experience within the past hour.
2. How did the old art of alchemy help to initiate the science of chemistry?
3. How does ionization help to explain most chemical reactions?
4. Why does the molecular form of a gas, such as nitrogen or oxygen, always imply covalence?
5. Under what structural condition do atoms tend to take on a negative or a positive electric charge in ionization?
6. Explain what structural changes are believed to take place when an atom develops a positive or a negative valence of 1, 2, or 3.
7. How did the chemists of forty years ago describe the nature of chemical affinity?
8. What are some of the ways in which the process of electroplating affects your life?
9. Contrast the parts of the atom that are chiefly responsible for its chemical and its physical properties.
10. What scientific attitude is manifested by young boys who, like Edison, become very active in seeking chemical experiences?

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CHAPTER FOURTEEN

Chemical Changes Depend on the Physical Conditions and the Chemical Nature of Substances

Solutions Are Important in Chemical Reactions. In a previous chapter we discussed the phenomenon of diffusion. We shall now turn to a condition of matter commonly known as solution. Although the physical process involved when solutions are formed closely resembles diffusion, in some respects it is different.

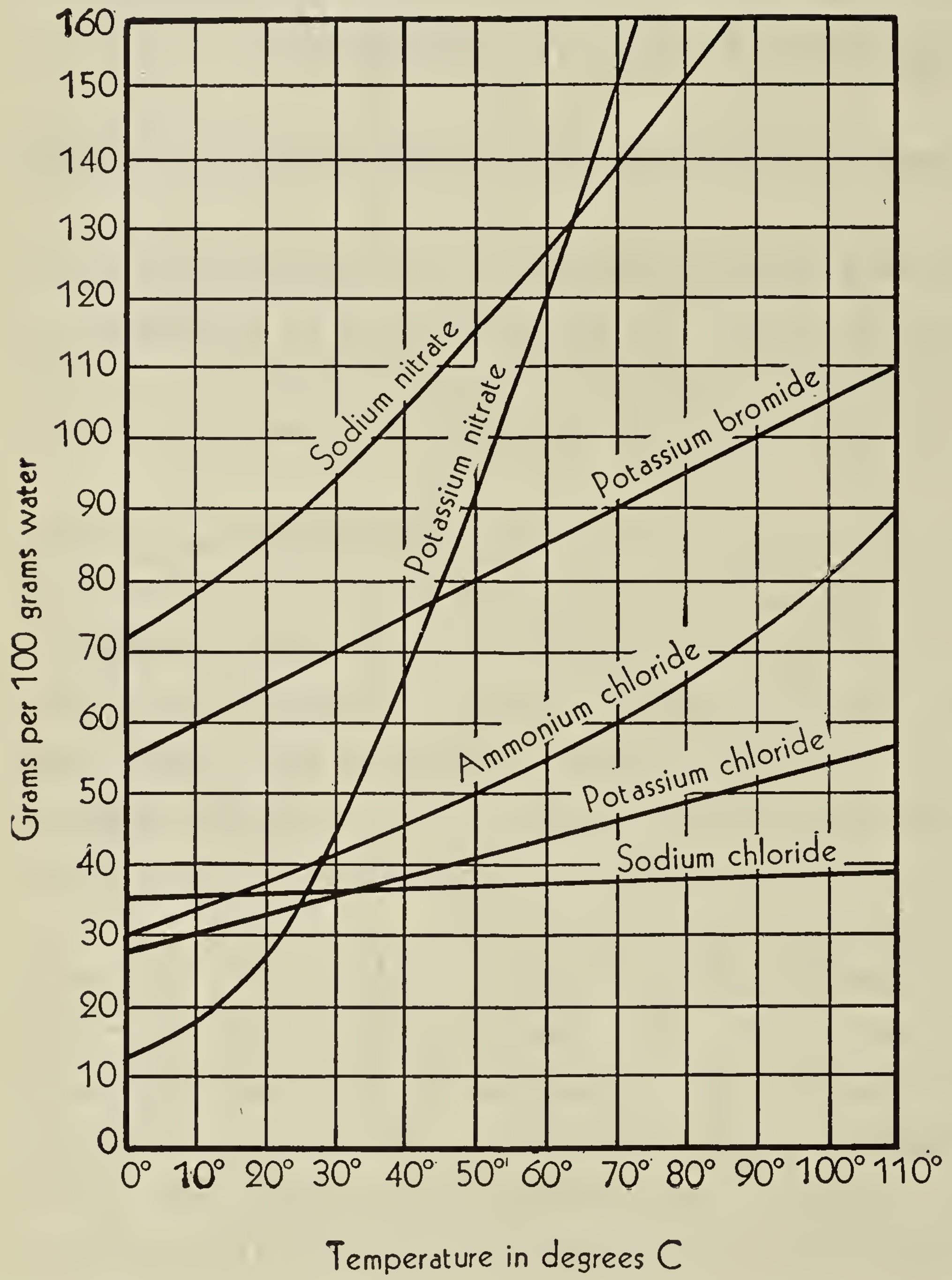
If one puts a lump of salt into a cup of water, the salt dissolves, or goes into solution. We cannot then see the salt, but we know it is in the solution because we can taste it, and if the water is evaporated the salt remains behind as a residue. The reason why the salt goes into solution seems to be that the water molecules pull the salt ions out of their position in the crystal more rapidly than the crystal pulls the salt ions back into their original position. The result is an increasing number of freely moving salt ions in the water, or, as we say, the solution becomes more concentrated.

When many of the salt ions have been set free in the liquid, the water molecules apparently tend to attract those already pulled loose instead of attracting other ions from the salt crystal. Consequently the dissolving power of the water under this condition grows weaker and weaker until the system finally reaches equilibrium. That is, no more ions are pulled out of the crystal structure than go back into it. Chemists then say that the solution is *saturated.*

Solutions are of tremendous importance in connection with chemical changes. We could not live without them. Our digestive systems must convert the food we eat into soluble substances which can be absorbed and transported through the body by the plasma of the blood. Oxygen, likewise, must be dissolved before it can be utilized in the cells. In fact, the whole round of organic activities which we recognize as constituting life takes place largely in solutions.

Solution is of equal significance in promoting chemical reactions in the inorganic world. It is in solution that freely moving electrically charged ions are formed. These are now ready to combine to form new compounds. Indeed, solutions are the arena of chemical change and its resultant products.

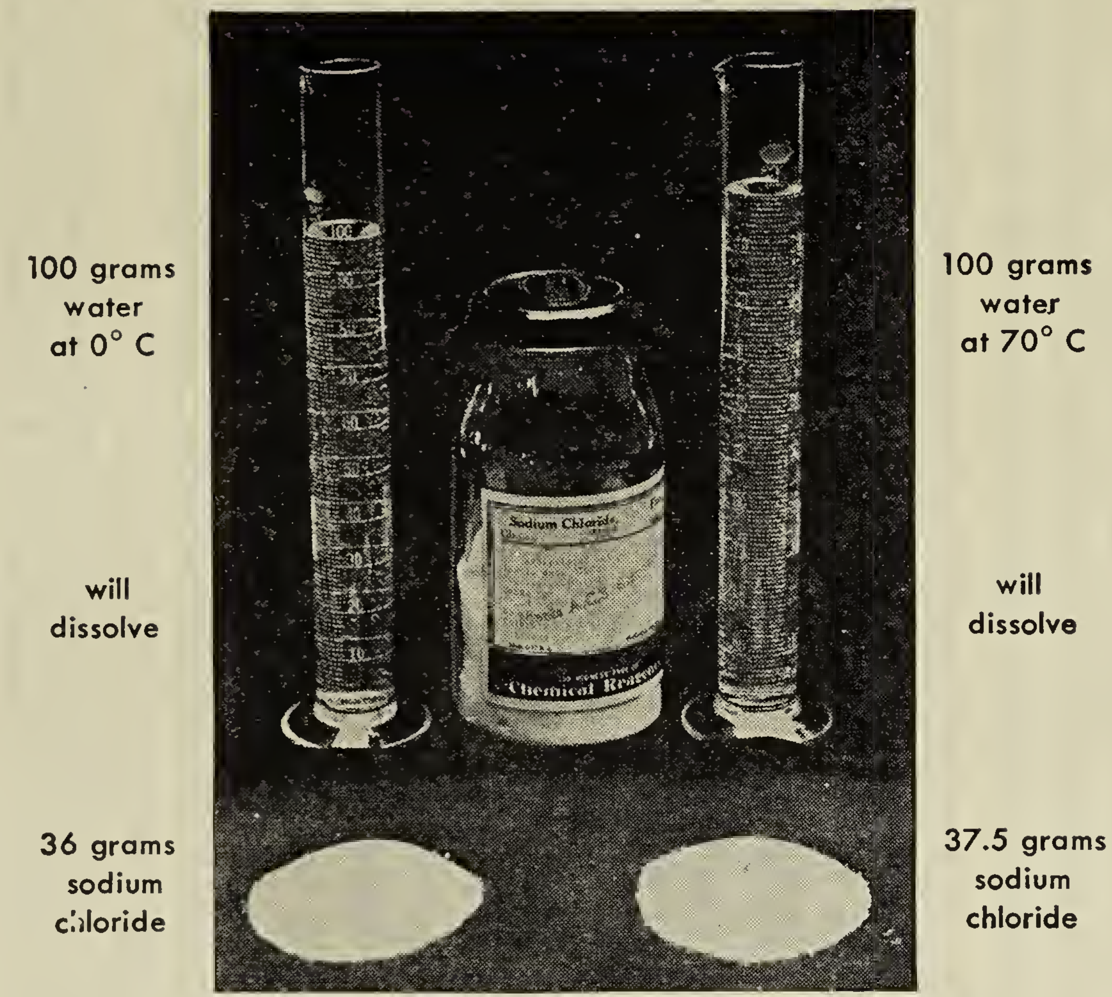
Though water is the most general *solvent,* there are many others. In fact, some substances cannot be made to dissolve in water, but readily do so in other solvents. Fats, waxes, and camphor remain undissolved in water, but easily go into solution in chloroform or ether. Most cleansing fluids for clothes contain fat-solvent substances for the purpose of dissolving out grease during the cleaning process.



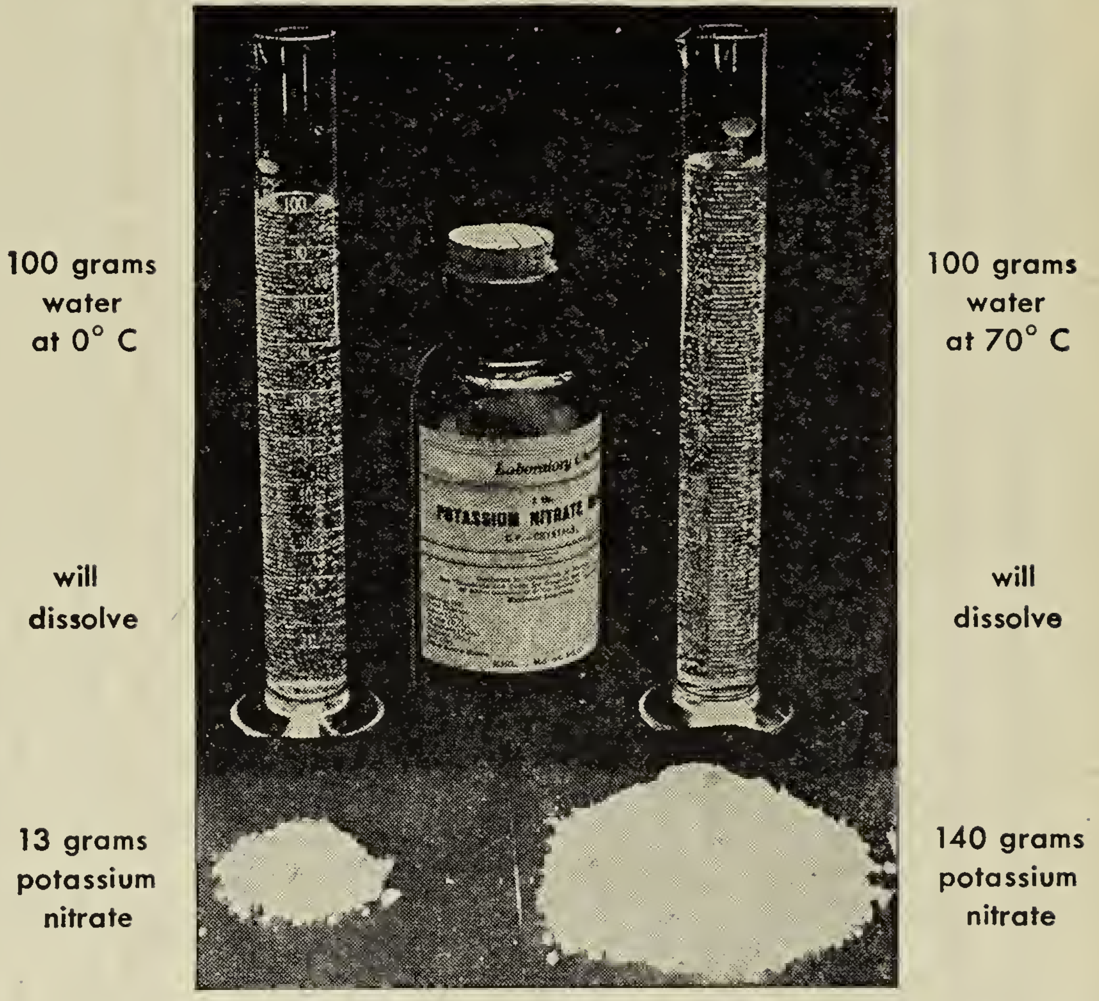
The graphs show that solubility increases with increasing temperature

In dissolving substances heat is an important factor. The housewife heats the sugar and water in order that it may go into a sirupy solution more quickly. The heat when applied to the undissolved *solute* causes the molecules to vibrate more rapidly. Consequently they fly farther apart in their crystal structure, and the force which holds the molecules together in the crystal is thereby reduced. Now the attractive pull of the solvent molecules is more effective, and the solid goes into solution more readily.

The concentration of a solution affects both its freezing point and its boiling point. A concentrated salt solution, for example, freezes at a lower temperature and boils at a higher temperature than a dilute solution will. This fact is of great practical value. A handful of salt in the plumbing trap keeps it from freezing and bursting in cold weather, and in ice plants the cubes of ice are frozen by circulating about the water-containers a calcium chloride solution the temperature of which is below the freezing point of water. This same solution is used as a cooling agent in refrigerator cabinets in drugstores and in meat markets because its molecular groups freely dissociate. In candy-


100 grams water at 0° C
will dissolve
36 grams sodium chloride
100 grams water at 70° C
will dissolve
37.5 grams sodium chloride

The effect of temperature on the solubility of sodium chloride


100 grams water at 0° C
will dissolve
13 grams potassium nitrate
100 grams water at 70° C
will dissolve
140 grams potassium nitrate

The effect of temperature on the solubility of potassium nitrate making the boiling point of the sugar solution gradually rises with increased concentration. Consequently the end of the cooking process is indicated when the candy thermometer reaches a certain temperature.

The Rate of Chemical Change Is Dependent upon Several Factors. The rate of chemical reactions is influenced by the size of the particles. For instance, the more finely a reacting solid is divided, the more surface is exposed and the higher the rate of reaction. Fine shavings will burn much faster than a log. The nature of the substances also affects the rate of reaction. Relatively speaking, wood burns slowly when ignited, but gunpowder, if confined, burns very fast, that is, explodes with terrific force.

Heat is another condition which affects the speed of chemical reaction. As every housewife knows, baking soda when added to hot sour milk or vinegar reacts much more rapidly than when the milk or vinegar is cold. So fast is the speed of reaction when the substances are hot that a raging effervescence forthwith results.

Van't Hoff, acclaimed in his time as "the greatest living physical chemist," gave us an important law in connection with the influence of heat on the rate of chemical reaction. Within practical limits it may be stated thus: *The speed of a chemical reaction is doubled with every 10° C rise in temperature.* A simple calculation will reveal at once the importance of this law. Let us suppose that a certain chemical reaction requires one second for its completion at 0° C. If the temperature is raised to 100° C, the same change will take place in just about one thousandth of a second; and if the temperature is raised to 200° C, the time required for the change will be approximately one millionth of a second. On the other hand, a chemical reaction that would require one second at 200° C would need a million seconds, or about eleven and a half days, at 0° C. Thus temperature, it may readily be seen, is of the greatest importance in connection with chemical change.

There is another way in which the speed of a chemical reaction may be profoundly changed. In the earlier part of the last century it was discovered that the rate of many chemical changes can be greatly influenced by the addition of a minute quantity of some other substance. In some instances the amount of the third substance required is extremely minute. For example, hydrogen sulfide (H_2S) unites with oxygen very slowly, if at all, under normal conditions. But if the gas is first absorbed by powdered charcoal and then oxygen is passed over the mixture, the two gases unite vigorously. Combination is usually so rapid as to ignite the charcoal.

Another example is furnished by oxygen and hydrogen when they combine to form water. If every trace of moisture can be removed, a mixture of the two gases may be heated well up toward 1000° C without a union of the two being accomplished. But if a trace of moisture is added, they combine so rapidly at about 600° C as to produce a violent explosion. Most students have experienced this effect in the chemical laboratory by touching a lighted match to soap bubbles inflated with hydrogen gas. The bubbles explode instantly with a loud report.

Some substances appear to act merely by their presence and, by "arousing the slumbering affinities of the substances," allow them to react. The term *catalysis* (Greek *kata*, "down" + *lyein*, "to loose") was introduced to designate their effect. A substance which facilitates a chemical change is known as a *catalyst* or *catalytic agent.* One writer has stated that a catalyst is like a tip given a waiter in that it hurries along a process which otherwise would proceed with inconceivable slowness.

A marked characteristic of catalysis is the minute quantity of the catalyst generally required to accelerate the process. Thus, when a solution of sodium sulfite (Na_2SO_3) is being oxidized into sodium sulfate (Na_2SO_4), one ounce of copper in the ionized condition will accelerate the reaction in over 1,500,000 barrels of the solution.

Just how a catalyst acts is not fully understood. Its action in some cases seems to be connected with the large amount of surface exposed on its finely divided particles. In other cases its effect is apparently due to a weak, intermediate, momentary chemical combination formed between one or more of the original interacting substances and the end product. But whatever its action, the catalyst does not appear in the final products formed. Ostwald makes this clear when he defines a catalyst as "any substance which, without itself appearing in the final products of reaction, alters the velocity with which that reaction takes place."

The principle of catalysis is much used in industries which involve the application of chemistry. In the synthesis, or artificial production, of ammonia, in the manufacture of marsh gas, and in the hydrogenation of vegetable oils to form solid fats for kitchen use, catalysts are employed. The Bergius process of forming gasoline from coal, practiced extensively in some European countries, also involves the use of catalytic agents to speed up the rate of the chemical changes involved.

Chemists are generally interested in speeding up chemical processes, but sometimes they wish to slow them down. There are *negative catalyzers*, which decrease the velocity of chemical reactions, as well as positive catalyzers, which increase them. A familiar example is that of antiknock gasoline. The "knock" is due to the fact that the last part of the "gas" charge in the cylinder of the engine burns almost instantaneously and is accompanied by a rapid rise in pressure. This difficulty is largely overcome by adding to the gasoline lead tetraethyl, a negative catalyzer, which acts as an antiknock by slightly slowing down the rate of the gaseous explosion. Likewise gasoline forms gummy residues which in automobiles tend to clog the carburetor and "gas" lines. The use of negative catalysts, which act as inhibitors, has greatly reduced this difficulty.

Vulcanized rubber, used in automobile tires, rubber boots and shoes, and rubber raincoats, is subject to slow oxidation in the air, especially in the presence of light. This renders it stiff, brittle, and devoid of elasticity. Certain complex compounds which are added to the rubber retard this deteriorating change and greatly increase the life and serviceability of the articles.

Edward Buchner in 1897 proved beyond dispute that organic catalysts are produced by living organisms. He ground yeast cells in sand to break down their walls and then added water to the mass. After standing for a time the liquid was filtered off, leaving behind the residue of sand and ground-up yeast plants. When the liquid was added to a sugar solution, it readily speeded up the fermentation process, resulting in the production of alcohol and carbon dioxide. In this way Buchner was able to show that alcoholic fermentation is accelerated not by the direct action of the yeast cells themselves but by an organic substance, called *zymase*, which they produce. It is because of the fact that these catalysts were first found in yeast plants that the general name *enzymes* (Greek *en*, "in," and *zyme*, "leaven") was applied.

Enzymes are indispensable to all living organisms. They are necessary to speed up the chemical processes required to sustain life. Without enzymes, changes of this character could go on to some extent within the relatively low range of temperature maintained by the bodies of living organisms, but the rate of action would be entirely too slow to preserve life. For this reason, were it not for the secretion of gastric enzymes to hasten digestion, man would starve to death with a stomach full of food. Intestinal digestion is also accelerated by enzymes. Practically all, if not all, physiological changes are believed to be speeded by these organic substances. In the synthesis of carbohydrates, the building of fats, the elaboration of proteins, the production of protoplasm, and the oxidation of organic fuels to liberate energy, enzymes are believed to play a leading role. Indeed, as our knowledge of enzymes grows, it is becoming almost impossible to envisage any living process whatever whose speed is not materially accelerated by these organic catalyzers.

The speed and character of a chemical change are also influenced by the nature of the combining substances. In this respect few compounds are more active than bases and acids. Moreover, within these two groups of chemical substances are found compounds which are closely connected with the average person's daily experience. The person with gastric hyperacidity (excessive acid in the stomach) seeks to correct this condition by taking some alkali, such as baking soda or milk of magnesia. In thus securing relief he is merely employing the chemical principles involved in the reaction between bases and acids.

Acids. The outstanding characteristic of acids is that they always contain hydrogen, combined with other nonmetals or nonmetallic radicals, and this hydrogen may be replaced either wholly or in part when the acid acts with a base (see page 213). For example, in hydrochloric acid (HCl) the hydrogen atom is combined with a single chlorine atom; in sulfuric acid (H_2SO_4) the hydrogen is bound with the sulfate radical, SO_4. In these acids all the hydrogen may be set free as hydrogen ions. Since the ionized hydrogen atom is stripped of its single electron, it in reality then becomes a proton, which we may indicate thus:[1] H^+. For this reason acids are sometimes spoken of as proton-donors. When HCl dissociates, the chlorine atom takes on the electron from the hydrogen atom and becomes Cl^-. Dissociation of the sulfuric acid means that two H^+ ions are released and that the sulfate radical has appropriated the two electrons, assuming thereby the condition $(SO_4)^{--}$.

It is these positively charged ions that give acids in solution their sour taste and their ability to turn blue litmus red. Findlay, a well-known British chemist, states that "*an acid is a substance which in solution gives rise to hydrogen ion, and acid properties are the properties of hydrogen ion.*"

It is also the proportional amount of this ionized hydrogen which determines the strength of an acid. For instance, a 5 per cent water solution of hydrochloric acid is very strong, while a 5 per cent solution of acetic acid may be used on our dining table as vinegar. Each has the same proportions of the acid to the water, but the difference lies in the fact that the hydrochloric acid is much more highly dissociated than the acetic acid and hence has many more free H^+ ions in a unit volume. For example, under certain conditions of temperature and concentration, the chemists have found that 90 per cent of the hydrogen atoms in HCl appear as H^+ ions, whereas only from 1 to 10 per cent of the acetic acid ionizes to set the H^+ ions free. Hydrochloric acid dissociates more readily than any other acid known; hence it is the most active. Nitric acid follows as a close second, with sulfuric acid third. Among

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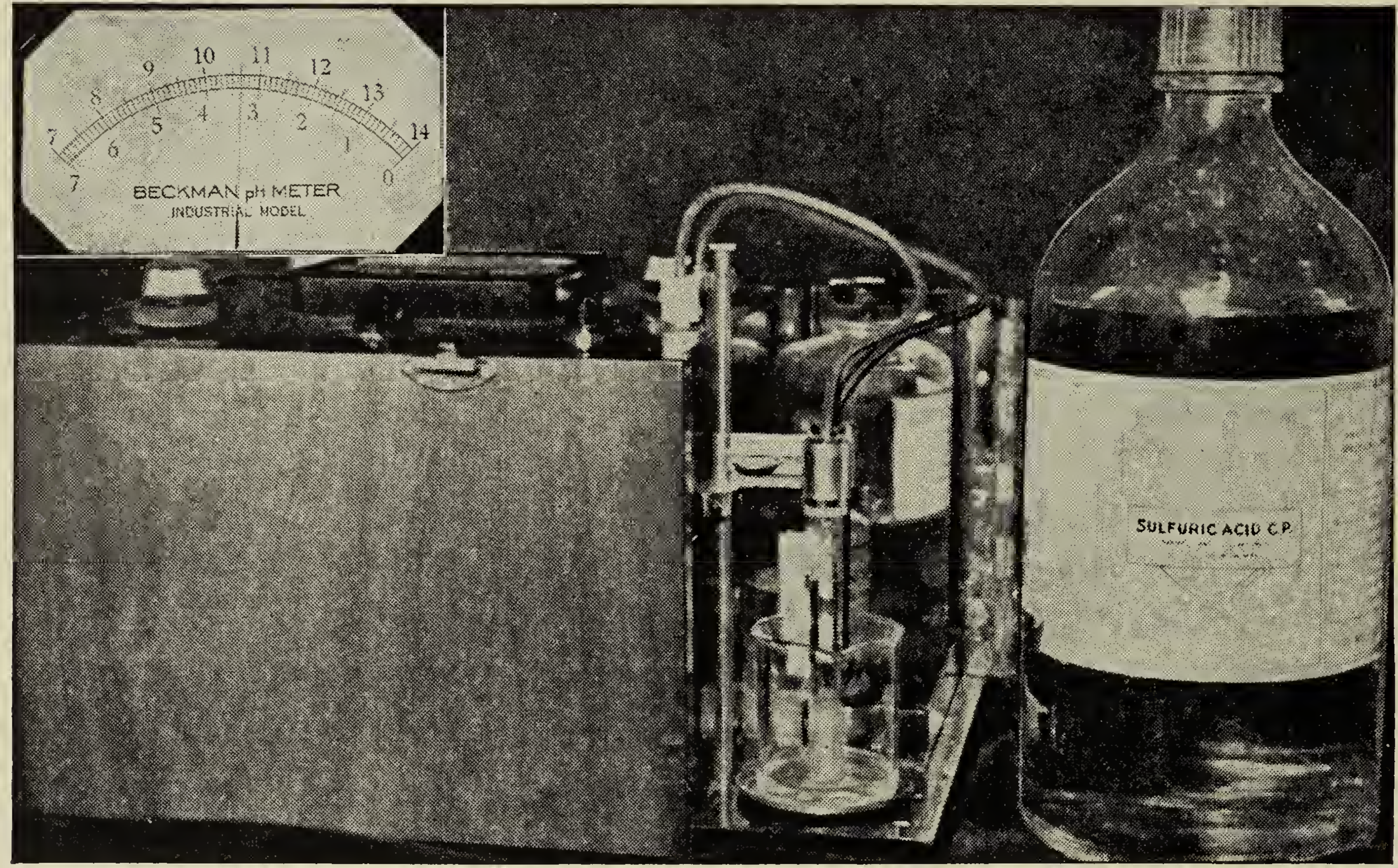
[1] Although in aqueous solutions most of the hydrogen is believed to be loosely combined into hydronium ion (H_3O), that condition, for the sake of simplicity, is disregarded in this volume. If one remembers this principle, little error can arise from regarding the hydrogen as free ions.



The potentiometer measures the strength of an acid in terms of its hydrogen ions

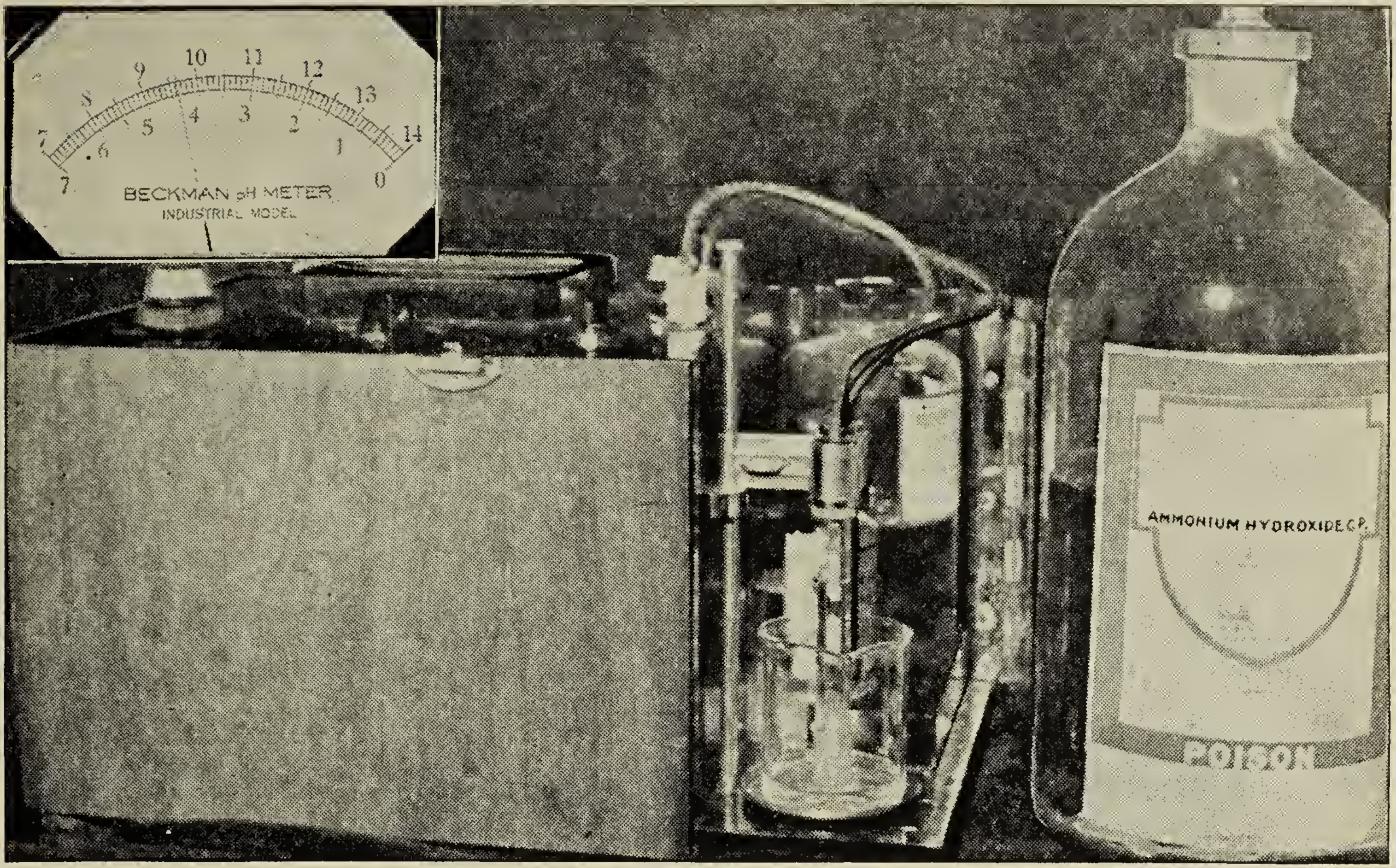
The strength of the acid used can be read by the lower curve of figures on the face of the scale

the weaker acids are acetic acid ($C_2H_4O_2$), carbonic acid (H_2CO_3), and phosphoric acid (H_3PO_4), the last of which is somewhat more active than the other two.

Chemists indicate the acidity and the alkalinity of solutions by what is called their *p*H value or H ion concentration value. A value of 7.0 is considered neutral, with anything above that point indicating alkalinity and anything below indicating acidity.

Bases. Bases are substances having properties complementary to those of acids. They usually consist of a metal or a metallic-like group combined with the hydroxyl radical, as in the case of sodium hydroxide (lye) ($NaOH$), used for soapmaking and sometimes for cleaning. Other examples of bases are calcium hydroxide ($Ca(OH)_2$); potassium hydroxide (KOH), which is potash lye; and aqua ammonia (NH_4OH). In general, these compounds are bitter to the taste and turn red litmus paper blue. They readily dissociate to set free positive ions, such as Na^+, K^+, Ca^{++}, NH_4^+. After dissociation the hydroxyl ions, $(OH)^-$, readily combine with the hydrogen ions, H^+, of an acid to form water. Under proper conditions the metallic ion or radical of a base readily combines with the acid radical to form a new compound called a salt.

Bases are abundant in the universe. Moreover, since there is always a



The potentiometer is also used to determine the strength of a base

The strength used in this instance can be read by the upper curve of figures on the face of the scale

tendency when the two are brought together to make the exchanges outlined above, the reactions between bases and acids are among the most common chemical reactions known to man. The carbon dioxide liberated in such large quantities from respiration, combustion, and decay unites readily with water to form carbonic acid (H_2CO_3), which in turn, as we shall see later, is a very important and universal agent in decomposing rocks to form soil. When the housewife uses sour milk in baking, she almost invariably uses baking soda too. When the two are brought together, there is always a "great stir," a rapid effervescence of carbon dioxide gas, which is one product formed by the hurried shifting of ions as neutralization takes place. When vinegar stains steel cutlery, the acids are attacking the metal to form iron compounds.

Salts. The product formed when the positive ions of a base take the place of the positively charged hydrogen ions of an acid, and thus unite with the negatively charged ions of the acid, is called a *salt.* Water too, as we have seen, is formed as a second product. Thus

$$2\,NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2\,H_2O$$

Here the sodium sulfate formed is the salt. The chemist in such reactions often speaks of neutralizing the acid with a base and calls the process *neutraliza-*

tion. If the reactions between the bases and the acids which form salts are complete, so that none of the hydrogen ions are left in the resulting compound, then the salts produced are chemically neutral. The sodium sulfate indicated in the reaction above is a *neutral salt.* Sometimes, however, the action is not complete, so that some of the hydrogen atoms are left in the resulting molecules. Salts so formed are said to be *acid salts.* Sodium acid sulfate ($NaHSO_4$) furnishes a good example.

There are also *basic salts*, which yield on dissociation two different kinds of negative ions. Basic ferric acetate furnishes a good illustration. It ionizes thus:

$$Fe(OH)_2C_2H_3O_2 \longrightarrow Fe^{+++} + 2\ OH^- + C_2H_3O_2^-$$

There are also salts which give basic reactions because of the combination of a strong base and a weak acid. Sodium carbonate (Na_2CO_2) is a salt of this type. Salts are generally crystalline, and many of them are soluble in water. For these reasons this class of chemical substances is most important to all forms of living things, plants as well as animals. For example, most of the minerals available to plants in the soil are in the salt form and must be dissolved in water before the plant can utilize them. The mineral accessory foods used by animals are also salts. Indeed, the acids, such as vinegar and those in fruits, are rapidly transformed into salts in the body, which aid in keeping the blood neutral and thus prevent acidosis. These are some of the reasons why one should always include green vegetables, which contain minerals, and fruits, with their acids, as parts of his normal diet.

Oxidation and Reduction Constitute an Important Chemical Reaction. There is another type of chemical reaction so important in the universe that it becomes necessary to give it some attention in this connection. It is known as oxidation and reduction, and plays an extremely important role in man's affairs, as well as in the processes of nature.

Lavoisier was able to show that combustion is a combining of the combustible material with the oxygen of the air, as is also the process of rusting. He showed, however, that the rust formed when iron is combined with oxygen actually weighs more than the iron itself.

At first the term *oxidation* meant a process of direct union with oxygen. Subsequently, however, it acquired a much broader meaning. This expansion in meaning was shown when the word was applied to the direct union of a substance with *any nonmetallic element*, such as oxygen, chlorine, or sulfur. For instance, metallic sodium burns vigorously in chlorine gas. The reaction may be expressed thus:

$$Na + Cl \longrightarrow NaCl + \text{heat}$$

This reaction is a true oxidation, although the element oxygen is not involved. When the metal zinc combines with sulfur to form zinc sulfide (ZnS), we have another example of oxidation without oxygen.

Atoms of metallic sodium or zinc, since they are electrically neutral, are devoid of valence. But the sodium in sodium chloride has a plus valence of 1, and zinc when combined with sulfur has a plus valence of 2. For these reasons the term *oxidation* has come to be applied to any chemical process in which the valence becomes *more positive* or *less negative.*

The chemical principle complementary to oxidation is called *reduction.* This term was used originally to mean any process by which oxygen is removed from a substance. But its later usage, like that of oxidation, has come to be more inclusive. Moreover, its nature is the opposite of oxidation. For reduction denotes any chemical process in which the valence of an element becomes *less positive* or *more negative.*

The outstanding characteristic of these two processes, oxidation and reduction, is an electron shift. *Oxidation involves a loss of electrons, which always increases the positive charge on the atom or radical, whereas reduction means a gain of electrons, which always adds to the negative charges carried by the atom or radical.* In other words, electrons are transferred from one kind of atom, which is thereby oxidized, to another kind of atom, which is at the same time reduced. Oxidation and reduction, then, always go together, and the essential fact of the processes is an electron shift, or transfer. The substance that yields, or loses, the electrons compels something else to accept them. For this reason the former becomes the reducing agent and the latter the oxidizing agent.

For example, let us suppose that we have electrically neutral hydrogen and oxygen atoms. It will be remembered that in neutral atoms the orbital electrons just balance the nuclear protons. Let us see, then, what happens when the hydrogen is oxidized, or burned. For simple illustration we may designate the electrically neutral atoms thus: H^0 and O^0. But, according to the theory, before these two elements can combine chemically, charges of opposite kinds develop on the atoms, which ionize them. Thus

$$2\,H^0 + O^0 = 2\,H^+ \text{ and } O^{--}$$

Now in ionization electrons have shifted from the hydrogen atoms, which have thereby become oxidized, to the oxygen atom, which has thereby become reduced. Completing the reaction we get this result:

$$2\,H^+ + O^{--} \longrightarrow H_2O$$

which gives water for the final product.

In practice we speak of the reaction as oxidation. In reality it would be just as proper to speak of it as reduction. Perhaps it would be more nearly accurate to call it an *oxidation-reduction* process.

But if we follow what is often popular usage and speak of oxidation as one thing and reduction as another, then it becomes evident at once why oxidations and reductions are so important. They are our chief source of power and power storage. Boilers in industrial plants are raised to a high working pressure by the shift of electrons from the carbon to the oxygen atoms involved in the oxidation, or burning, of coal. All living organisms, including man, derive their metabolic heat and energy from the oxidation of food in every living cell of the body. TNT gets its highly explosive burst of power in the same way, except that the shift of electrons here is infinitely more rapid. Our automobiles are driven along the highways with the speed of an express train by the energy released in this combination of carbon and hydrogen with oxygen.

The opposite process of reduction is illustrated by food-making in plants, the form of reduction that means most to the world. The whole synthetic chemical reaction whereby carbon dioxide and water are combined into sugar and other carbohydrates is nothing more than a process of reduction carried through on a grand scale. Here the sunlight furnishes the power, and the liberated oxygen molecules diffuse off from the leaves of the plant in constant molecular streams. Work is done in the forming of sugar molecules, reduction results, and tremendous quantities of power are stored in the carbohydrates. Indeed, directly or indirectly, this is man's sole source of physiological energy. Likewise the further reduction process carried on by geological forces, which resulted in the conversion of this plant material into coal and oil, is the chief source of man's industrial power. Truly green plants, when energized by the rays of the sun, are the great chemical reducing agents of the world.

Questions for Study

1. How are solutions involved in your everyday life?

2. Why will heating a quantity of sugar and cold water cause a sirup to be formed more quickly than if the ingredients are left unheated?

3. Explain why, when sirups are boiled to make confections, the temperature of the sugary liquid, as indicated by the candy thermometer, gradually rises.

4. Why in making candy is temperature the best criterion of sufficient boiling?

5. The salt solution in which eggs are sometimes preserved for winter use can withstand a lower temperature without freezing than pure water can. How would you explain this fact?

6. It has been said that without pepsin or trypsin in the alimentary canal a man would probably starve to death with a stomach full of good food. Explain.

7. Why does Ethyl gasoline cause less fuel knock, or "ping," when used in an automobile than the same grade of untreated gasoline?

8. How would you explain the action of buffer salts in the blood?

9. Why is it desirable to eat foods, such as fruits and vegetables, with a good supply of the alkaline metals in them?

10. How are electrons believed to be involved in the energy release of fuel burned in a furnace?

11. How would you distinguish between oxidation and combustion?

12. How do acids differ from bases?

13. Just why are most salts said to be neutral?

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CHAPTER FIFTEEN

Organic and Colloidal Chemistry Are Involved in Life Processes and in Many Reactions of Value to Man

Modern Organic Chemistry Had Its Beginning in the Work of Wöhler. The first breach in the wall separating inorganic and organic chemistry may be said to have been made by the German chemist Friedrich Wöhler. Berzelius, as late as 1827, had maintained that although inorganic compounds could be prepared artificially in the laboratory, organic compounds could be produced only by living plants or animals.

The foundations of that position, however, were already being sapped. For in 1828 Wöhler, then a schoolteacher in Berlin, succeeded in a revolutionary achievement. By heating an inorganic product called ammonium cyanate (NH_4CNO) he was able to convert it into urea ($CO(NH_2)_2$), which is an organic compound. This substance appears in urine and had hitherto been known only as a product of the animal body. In triumph Wöhler wrote to Berzelius, "I must tell you that I can make urea without the need of kidneys or of any animal whatever."

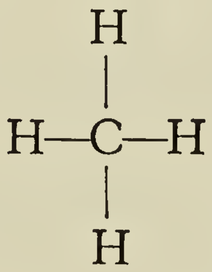
The synthesis of urea remained for a number of years the only example of the artificial production of an organic product. In time, however, others were synthesized, and gradually the wall between the organic and the inorganic world was laid low. Although these two branches of chemistry are recognized today, the line of demarcation is not nearly so distinct as was formerly supposed. Indeed, hundreds of organic products can now be prepared in the laboratory.

Moreover, the advances of organic chemistry have dealt the theory of vitalism a staggering blow, for this force is not now regarded as the potent one that its earlier adherents asserted it to be. If a vital force exists at all, it is so closely connected with chemical and physical processes as to defy separate identification by any methods of analysis known today.

The Term *Organic Chemistry* Has Taken on a Changed Meaning. From the work of Wöhler and chemists who followed him, one conclusion became clear. No exclusive distinction could be made between inorganic and organic substances on the basis of either their origin or their association with any living body, either plant or animal. The distinction as now drawn rests upon a different basis. As one author puts it, "For the purposes of classification, it has been found justifiable and convenient to draw such a distinction on the basis of the chemical behavior of the element carbon itself, an element which is present in all the compounds formerly classed as organic." Consequently the term *organic chemistry* has come to mean the chemistry of the carbon compounds.

A recent estimate places the number of known compounds that contain carbon at 250,000. This is about twice as many as have been discovered for all the other elements together. However, the vast array of carbon compounds is not so baffling to the student of this branch of chemistry as the number might lead one to infer. For there are beautiful chains of relationships running through the different groups which enable chemists to marshal them into orderly ranks and files of great significance. We shall have time to note but a few of these relationships. Our attention will be directed rather toward some of the valuable carbon products which are closely connected with everyday experience.

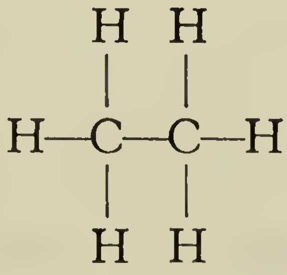
Important Groups of Hydrocarbons. We should begin the study of organic chemistry with the simple combination of carbon and hydrogen called *methane* or marsh gas. Substances composed of only carbon and hydrogen are known as hydrocarbons. The arrangement of the atoms in the molecules of marsh gas is pictured as follows:



$$\begin{array}{ccc} & H & \\ & | & \\ H- & C & -H \\ & | & \\ & H & \end{array}$$

Thus carbon is seen to have a valence of 4. This gas is called marsh gas because it is produced in marshes by the decay of plant materials in water. It is also found in coal mines as a constituent of coal gas and also of the highly inflammable and dangerous firedamp. Carbon compounds such as methane, in which all the available valences of the carbon atoms are satisfied by combination with the atoms of some other element or of a radical, are said to be *saturated.*

The next carbon compound in the series is *ethane*, in which the carbon atoms are conceived as taking the following relation to the hydrogen atoms in the molecule:

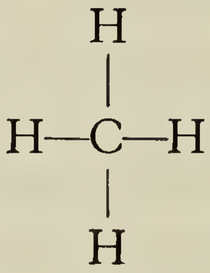


$$\begin{array}{cccc} & H & H & \\ & | & | & \\ H- & C- & C & -H \\ & | & | & \\ & H & H & \end{array}$$

Ethane is frequently found in the gas issuing from oil wells.

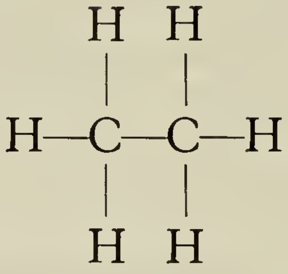
We find the third hydrocarbon in order of complexity to be *propane*, which has three atoms of carbon combined with eight atoms of hydrogen. This series is known as the paraffin hydrocarbons because paraffin wax is derived from certain forms of petroleum, which is a complex mixture of different hydrocarbons. The first six members of the paraffin series are

Methane (CH_4)



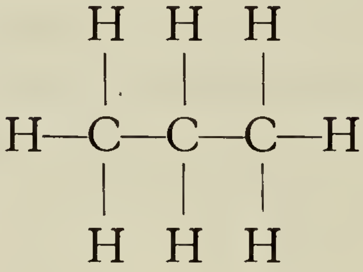
$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

Ethane (C_2H_6)



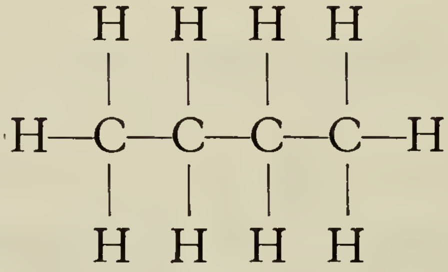
$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

Propane (C_3H_8)



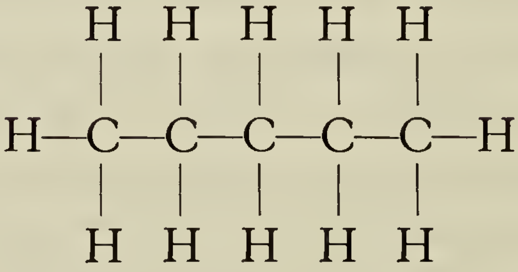
$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

Butane (C_4H_{10})



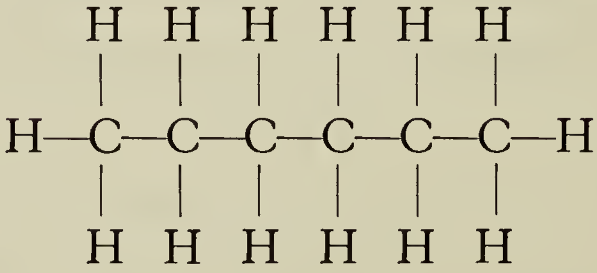
$$\begin{array}{ccccccccccc} & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & \end{array}$$

Pentane (C_5H_{12})



$$\begin{array}{ccccccccccccc} & & H & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & H & & \end{array}$$

Hexane (C_6H_{14})

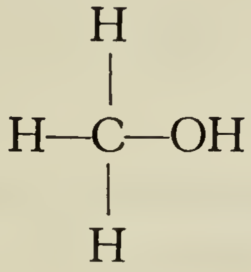


$$\begin{array}{ccccccccccccccc} & & H & & H & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & H & & H & & \end{array}$$

When some types of petroleum are distilled at their lower boiling points, certain of the less complex hydrocarbon compounds, such as gasoline and kerosene, are separated; when the crude oil is subjected to still higher temperatures, it yields more complex hydrocarbon products, such as lubricating oils and paraffin wax.

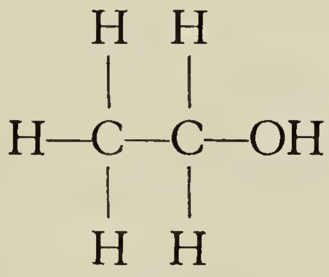
One or more of the hydrogen atoms in the members of the hydrocarbon series may be displaced by a halogen, such as chlorine, bromine, or iodine. If but one hydrogen atom is displaced by chlorine, for example, an organic compound called alkyl chloride is produced. The simplest of such compounds is methyl chloride (CH_3Cl). By using the different halogens as substitution agents and different members of the hydrocarbon series to combine with them, a long list of alkyl halides is thus made possible.

Alcohols. By displacing one of the hydrogen atoms of a hydrocarbon with a hydroxyl radical, an alcohol is formed. The simplest alcohol is methyl alcohol. It is known commercially as wood alcohol or wood spirit, being so designated because it is obtained as one of the products formed when dry wood is distilled.



$$\begin{matrix} & \mathrm{H} & \\ & | & \\ \mathrm{H}— & \mathrm{C} & —\mathrm{OH} \\ & | & \\ & \mathrm{H} & \end{matrix}$$

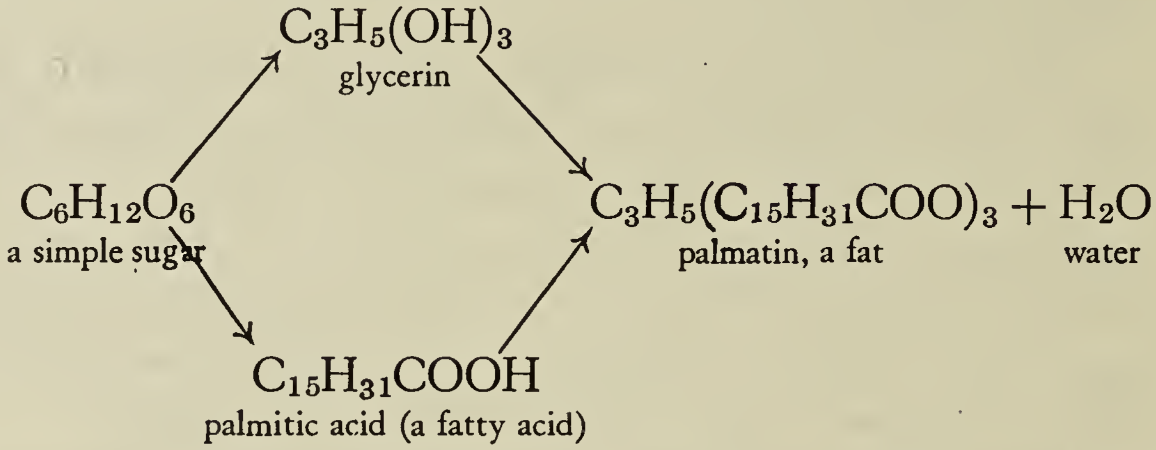
The next higher member of this series of alcohols is ethyl alcohol, graphically represented thus:



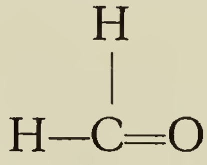
$$\begin{matrix} & \mathrm{H} & & \mathrm{H} & \\ & | & & | & \\ \mathrm{H}— & \mathrm{C} & — & \mathrm{C} & —\mathrm{OH} \\ & | & & | & \\ & \mathrm{H} & & \mathrm{H} & \end{matrix}$$

Its chemical formula may be expressed as C_2H_5OH. Ethyl alcohol is formed in nature by the action of yeast cells; it constitutes the grain alcohol of commerce. The intoxicating property of alcoholic beverages, such as wines, beer, and whisky, is due to the presence of this compound. Ethyl alcohol is rapidly becoming one of the components of motor and tractor fuels. Indeed, many agriculturists are hopeful that the use of grain to produce fuel alcohol will largely restore the consumption of the agricultural products lost when draft animals were displaced by motorcars, trucks, and tractors.

Alcohols are of great chemical importance in another way. They, together with the fatty acids (see p. 222), form what is believed to be intermediate steps in the synthesis of fats from sugar. This may take place in either the plant or the animal body. The relation in a plant may be shown theoretically, without any attempt to balance the results, as follows:

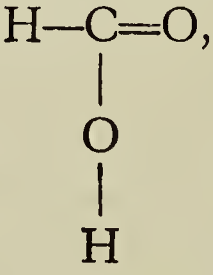


A similar synthesis is believed to take place in the animal body except that, in this case, stearin ($C_3H_5(C_{17}H_{35}COO)_3$) is formed instead of the palmitin $C_3H_5(C_{15}H_{31}COO)_3$.

Aldehydes. This group of compounds includes some of great utilitarian value. They are formed by a partial oxidation of the alcohols. The most common and well known of the aldehydes is formaldehyde, with the graphic formula  $\mathrm{H{-}\overset{\substack{H\\ |}}{C}{=}O}$. It is compounded by passing the vapor of methyl alcohol together with air over some catalyst, such as a heated copper or silver gauze, and collecting the gas in water.

At ordinary temperatures formaldehyde is a gas; and when it is dissolved in water, it produces a solution known as formalin. Formaldehyde, either as a gas or in solution, is used as a preservative, disinfectant, and germicide. Industrially it is employed in the manufacture of dyes, such as indigo, the hardening of photographic films, and the making of such artificial resins as Bakelite and Redmanol.

Organic Acids. A series of organic acids may be considered as derived from the hydrocarbons. They are produced by a more complete oxidation of the alcohols than is required to form the aldehydes.

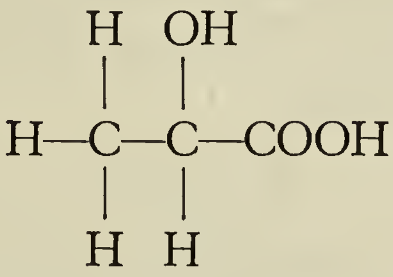
The simplest of the so-called fatty acids (related to the saturated, or paraffin, hydrocarbons) is formic acid. Its formula,  $\mathrm{H{-}\underset{\substack{|\\ O\\ |\\ H}}{C}{=}O}$, shows its relationship to methyl alcohol and methane. Insects, such as ants and bees, as well as certain nettles, produce formic acid. This product was formerly obtained by distilling red ants. The piercing pain from bee stings and the smarting sensation from nettle pricks are chiefly caused by formic acid which is deposited within the wound.

The chemical formula for formic acid is usually expressed as $HCOOH$. In this formula the $COOH$ group constitues the *carboxyl radical*, characteristic of certain organic acids.

The next higher organic acid in this series is acetic acid (CH_3COOH). It may be considered as derived from ethane. It is formed as a by-product when acetic acid bacteria oxidize ethyl alcohol. Weak dilutions of this acid, together with other organic compounds, form the common vinegar, used extensively in pickling and cooking.

Other more complex organic acids, related to formic, are common in everyday experience. The intensely sour taste of rhubarb is due principally to the presence of oxalic acid, which is a dibasic acid. Dibasic acids are formed when two hydrogen atoms are displaced by carboxyl radicals. Oxalic acid has the structural formula $COOH \cdot COOH$.

Sometimes one or more of the hydrogen atoms are displaced by carboxyl radicals, while in the same compound another hydrogen atom is replaced with a hydroxyl, OH, radical. This gives a special type of acid known as the *hydroxy acid.* Lactic acid ($CH_3 \cdot CHOH \cdot COOH$) is a good example. It may be pictured thus:



$$\begin{array}{ccccc} & & H & & OH & \\ & & | & & | & \\ H & — & C & — & C & —COOH \\ & & | & & | & \\ & & H & & H & \end{array}$$

This acid is produced in nature by the action of lactic acid bacteria and is characteristic of sour milk and other foods, such as sauerkraut. Silage, used chiefly as feed for cattle, contains large quantities of lactic acid, produced through fermentation in the silo. The lactic acid produced in silage and sauerkraut acts as a highly effective preserving agent to prevent further decomposition. The citric acid of oranges and other citrus fruits, and malic acid, found in apples, are more complex hydroxy acids.

Esters. Organic acids interact with alcohol to form esters. Esters differ in composition from ordinary salts in that they contain a hydrocarbon radical in the place of a metal. However, by heating an ester with a strong base, such as sodium hydroxide ($NaOH$), the metal ion (Na) can be made to replace the hydrocarbon radical, as illustrated in the following equation:

$$\underset{\text{ethyl}}{CH_3}\text{—}\underset{\text{ester}}{COOC_2H_5} + \underset{\substack{\text{sodium}\\\text{hydroxide}}}{NaOH} \longrightarrow \underset{\text{sodium acetate}}{CH_3\text{—}COONa} + \underset{\text{ethyl alcohol}}{C_2H_5OH}$$

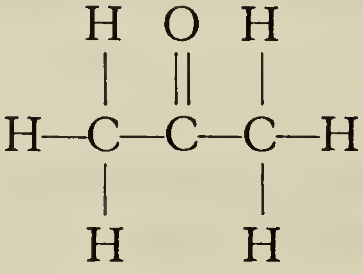
This reaction between an ester and a metallic base forming a salt and an alcohol is known as *saponification.* It is the reaction which takes place in soap manufacture. Soaps are made of low-grade animal fats and the cheaper vegetable oils, which are composed mainly of mixtures of three esters known as olein, palmitin, and stearin. When these esters are heated with an aqueous solution of a strong metallic base, saponification results. The following equation illustrates the change in the case of stearin:

$$\underset{\text{stearin}}{(C_{17}H_{35}COO)_3C_3H_5} + \underset{\substack{\text{sodium}\\ \text{hydroxide}}}{3\ NaOH} \longrightarrow \underset{\text{sodium stearate (a soap)}}{3\ C_{17}H_{35}COONa} + \underset{\text{glycerin}}{C_3H_5(OH)_3}$$

A similar type of reaction takes place when lactic acid is released from the muscle tissues into the blood. The acid combines with the sodium salt in the blood to form sodium lactate, a substance much like the sodium acetate and the sodium stearate in the reactions above.

A reaction of this type common to the household is the staining of steel knives with vinegar or the acids of fruits. In this instance the iron atoms replace the hydrogen atoms of the carboxyl radical, producing an iron salt which gives to the knife the dark color.

Ketones. Ketones are the products formed when a type of alcohol known as secondary alcohol is oxidized. The most common ketone is acetone, which has the following graphic formula:



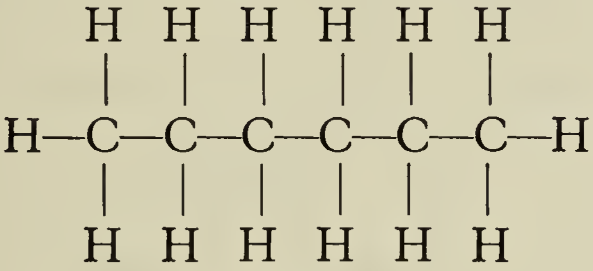
$$\begin{array}{ccccccccc} & & H & & O & & H & & \\ & & | & & \| & & | & & \\ H & - & C & - & C & - & C & - & H \\ & & | & & & & | & & \\ & & H & & & & H & & \end{array}$$

This compound is used in the manufacture of such products as chloroform, iodoform, smokeless powder, and celluloid.

Acetone is an excellent solvent for animal and vegetable oils and fats, and for gums and resins. For this reason it is used extensively in dry-cleaning establishments to remove grease spots from clothing, aside from certain rayons, which it dissolves. It is also employed as a constituent of paints, varnish-removers, and carbon-removers.

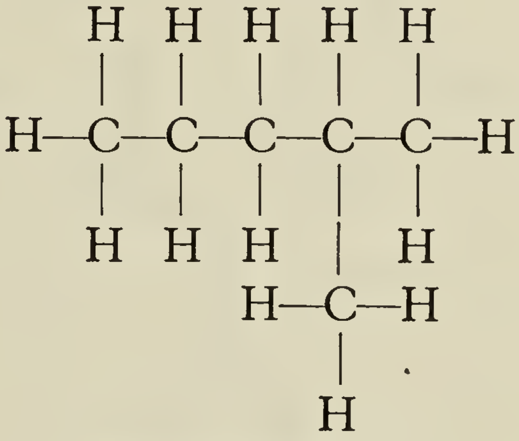
The Aliphatic Compounds Have a Chain Structure. All the organic compounds considered up to this point have been found to be formed by the carbon atoms that are arranged in rows, or "chains." In methane there is a single carbon atom. By combining other carbon radicals with this single carbon atom more complex substances may be formed. Even different carbon chains may be connected laterally to make more complex, branched compounds. There is no apparent limit to the complexity of organic compounds which may be formed by the extension or branching of such chains. Complex compounds of this type are known, and there are doubtless many others whose formulas have not yet been determined.

Organic compounds with the chain arrangement of the carbon atoms are *aliphatic compounds.* This term is derived from the Greek *aleiphatos,* genitive case of *aleiphar*, meaning "fat" or "oil," and is used because the formulas of all our fats and oils take this chainlike form. Although there may be some limitation to the chain structure, the aliphatic compounds "may be regarded as built up of 'chains' of carbon atoms, to which hydrogen and other atoms or groups of atoms are attached." The following formulas furnish a splendid example of how more complex aliphatic compounds may be built up. For example, when the methane radical is combined with hexane, dimethylpropylmethane is formed.



$$\begin{array}{ccccccccccccc} & & H & & H & & H & & H & & H & & H & \\ & & | & & | & & | & & | & & | & & | & \\ H & - & C & - & C & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & | & & | & \\ & & H & & H & & H & & H & & H & & H & \end{array}$$

hexane

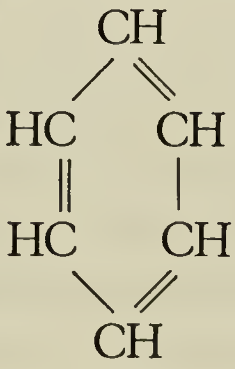


dimethylpropylmethane

The Aromatic Compounds Are Ringlike in Structure.

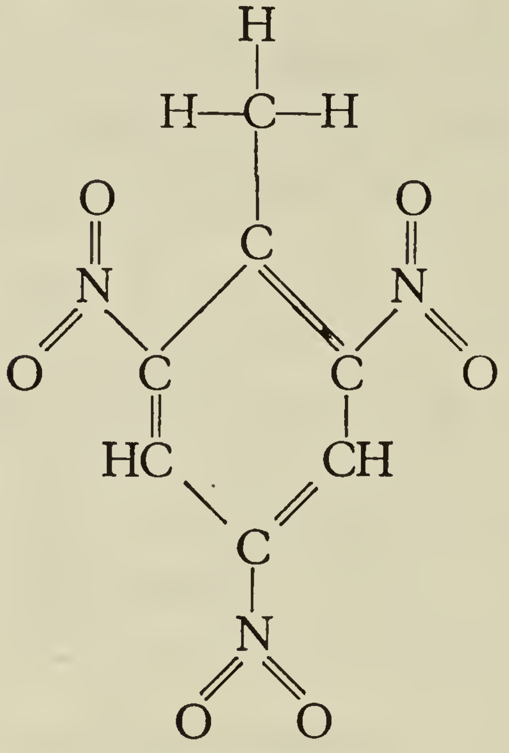
The aromatic compounds are so called because members of this group are the savory or fragrant components of volatile oils, such as oil of cloves and oil of peppermint, of spices, gums, and balsams. They constitute a very large and important group of the carbon compounds.

We found the aliphatic series to be built up by the addition of chain structures starting with methane as the fundamental substance. The aromatic series, however, is built around the *benzene ring.* Benzene, the simplest of the aromatic hydrocarbons, is an arrangement of six carbon atoms which may be pictured as a hexagon:

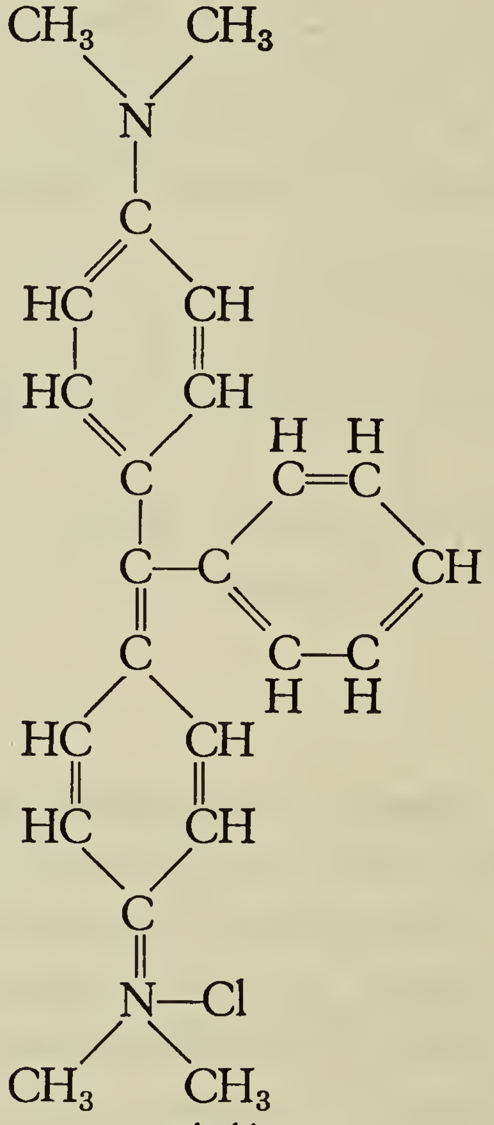


Benzene is one of the light derivatives obtained by distillation mostly of coal tar, a by-product of the coking ovens. In Europe thousands of tons of it are produced annually, much of which is used as a motor fuel.

Benzene rings, like the methane units, may be chemically tied together to form more complex substances. In addition, at each carbon atom other atoms or radicals may become attached. In this way an almost infinite series of compounds may be built up. The intricacy grows until the number and complexity of the atoms and radicals involved reach amazing proportions. The following formulas will give some idea of how the benzene ring may be expanded to form more complex aromatic compounds:



trinitrotoluol



malachite green

The structure on the left represents the powerful explosive TNT. The one on the right is for malachite green, one of the beautiful green aniline dyes.

There are literally thousands of these aromatic compounds and their derivatives. They include all the hundreds of aniline dyes, the coal-tar perfumes and flavors, and many explosives, preservatives, drugs, and disinfectants. They or their derivatives are used in the office, shop, and home. In fact, it would be difficult, if not quite impossible, to give an adequate idea in a limited space of the extent to which these compounds enter into the diverse and varied aspects of human life and experience.

Colloidal Chemistry Has Important Applications. We now come to a branch of chemistry called *colloidal* chemistry. Unlike the other phases of chemistry, colloidal chemistry is not concerned much with the composition of the molecules, but does lay great stress on their physical relationship. In the colloidal state the molecules, instead of being separated from one another, as in a true solution, are believed to be aggregated into tiny masses called colloidal particles. There are hundreds of organic colloids, and there are doubtless many more inorganic ones. Man's body is scarcely more than a mass of organized colloids, and the same is true of the tissues of a plant. It is especially for this reason that it will be of value to us to consider briefly colloidal substances and the important place which they occupy in the world of life and industry.

When a crystalloid, or crystalline substance, such as table salt, dissolves in water, the whole structure of the crystal lattice disappears. The ions leave their places in the crystal and become widely dispersed in the water. When this condition occurs, we have a true solution.

Contrasted with this crystalloid condition is the colloidal (Greek *kolla*, "glue" + *-oid*, "like") state. Interest in this field was first aroused by Thomas Graham, a Scottish scientist. In 1849 he delivered a lecture "On the Diffusion of Liquids," which was seventy-eight printed pages in length. As one writer facetiously remarks, that was "a lecture which would probably be unduly long for our modern audiences"; but it did mark the birth of colloidal chemistry. Graham discovered a useful and easy way to distinguish between *true* solutions and colloidal solutions. He had been working with parchment membranes and discovered that crystalloids would diffuse readily through them, but that colloids would not. By this method, called *dialysis*, colloidal substances could be separated from true crystalloid solutions.

The chief reason why colloidal substances will not diffuse through membranes is that the particles in a colloidal solution are not reduced to the dimension of molecules. In this state they are too large to get through the pores. Gelatin dissolved in water furnishes an example of a colloid. So does thin-boiled starch or liquid glue.

Colloidal solutions, then, it becomes evident, are not true solutions. We merely apply the term to these mixtures as a matter of convenience. Rather in so-called colloidal substances we have to deal with a heterogeneous system. A colloidal system in which water is the "solvent" consists of (1) the colloidal particles, called the *disperse* phase, and (2) the separating medium, the water, called the *dispersion* phase. These two parts of the system are also known as the *discontinuous* and the *continuous* phase, respectively.

It must be emphasized that colloids are not special kinds of substances. They are a special state, or condition, of substances. Indeed, under proper conditions it is believed that almost any substance, either inorganic or organic, may be made to take the colloidal state.

Sometimes the disperse phase is a solid as in roily water. Here the minute clay particles form the disperse phase and the water the dispersion phase. A colloid of this character is called a *suspensoid.* On the other hand, the disperse phase may appear as globules of one liquid dispersed in another liquid. The fat globules, or cream, dispersed in unskimmed milk is a good illustration. This kind of colloid is called an *emulsion.* The intense beating necessary to form mayonnaise dressing breaks the oil up into minute droplets and disperses the latter so completely that they are suspended in the vinegar. This is another example of a colloidal emulsion. We may find solid particles dispersed in a gas. Smoke in the air forms a colloid of this kind. Again, gases may be dispersed in a liquid. Beaten egg white and whipped cream are examples of this type of colloid, although in these cases most of the air bubbles formed are hardly minute enough to qualify as colloidal particles. There are still other kinds of colloidal systems.

The outstanding characteristic of a colloid is the nature of its dispersed particles. They are so finely separated as to furnish an amazing amount of surface. Suppose one takes a cube of charcoal just one square inch in area on each face. The total area presented, then, on the six faces is six square inches. Now, if we could divide it into cubes so fine as to form colloidal particles of just medium size, we should have just one quintillion (1,000,000,000,000,000,000) cubes, each with six minute faces. The total surface exposed on all these faces would be enormous. It would amount to approximately 41,656 square feet, or just about one fourth the area of an average-sized city block.

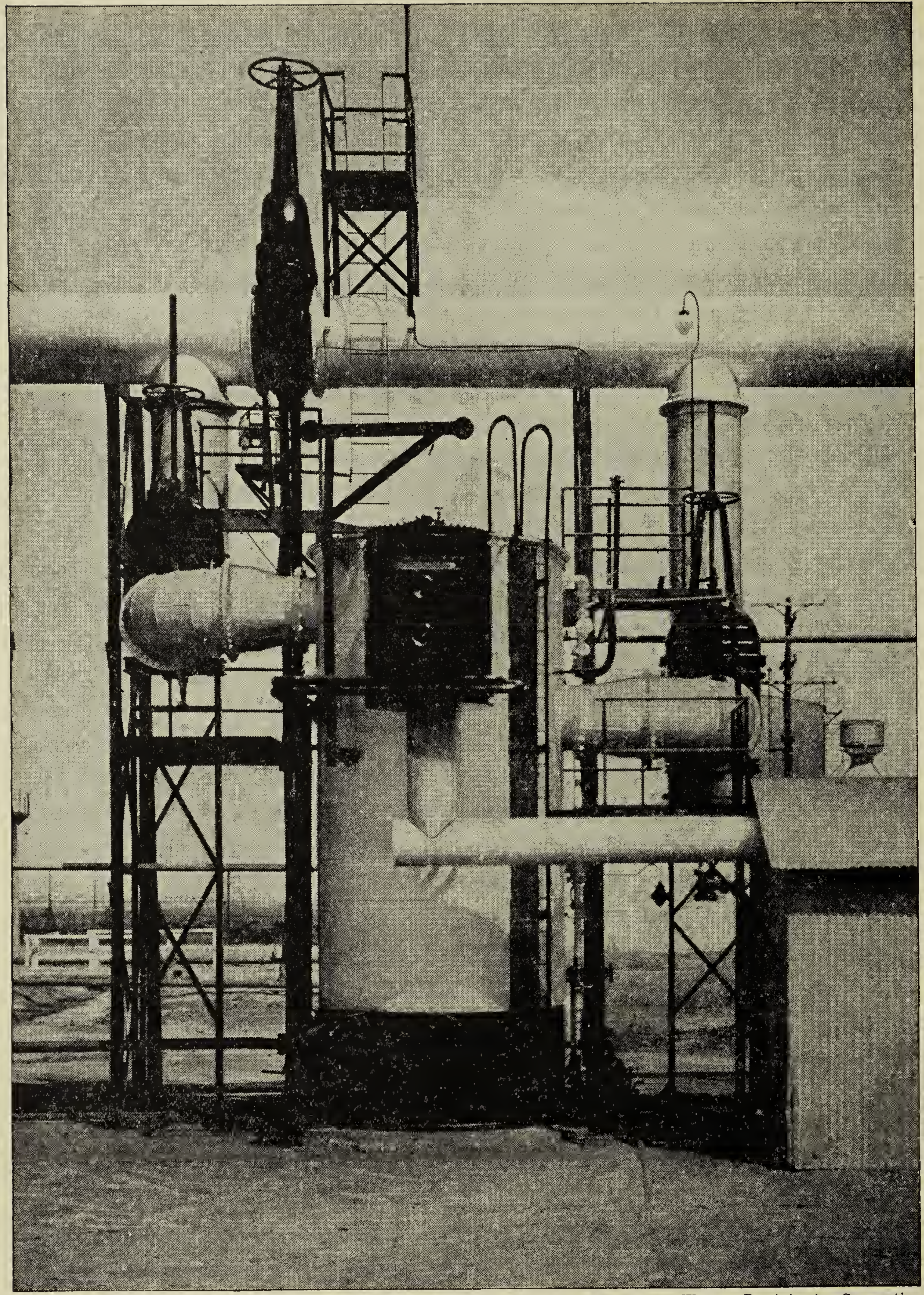
Another important characteristic of colloidal solutions is that the particles are electrically charged. The fact that all of them are covered with the same kind of charge causes them to repel one another. This is doubtless the most important force in keeping them in the dispersed condition. Sometimes this charge is positive in character; in other cases it is negative. For example, one may take a bottle of roily water in which the fine particles of clay are thoroughly dispersed and set it aside for weeks without the occurrence of any visible change. The water remains cloudy. But let some substance be added that will neutralize the charge, and a change quickly follows. The clay particles readily flocculate (aggregate into small lumps) and settle out, leaving the water perfectly clear. This principle is often made use of in clearing roily water for special uses.

Sols and Gels. Colloidal substances are found as either *sols* or *gels*, and which condition they assume depends on their degree of viscosity, or ability to flow. A sol may be defined as a colloidal system which appears to the eye to be a homogeneous fluid. It can be poured (more or less readily) from one beaker to another, but differs from a true solution in that its particles are aggregates of molecules instead of single molecules or ions. Gels, or "jellies," as some prefer to call them, on the contrary, are more or less rigid systems. They have such a high degree of viscosity that they will not flow, and because of this they tend to take on the properties of a solid. Household gelatin as it comes from the stove in the fluid condition is a sol; when it sets, or solidifies, it is a gel.

Most colloids can be transformed readily from one state to the other by changing the physical conditions under which they exist. In some instances this may be done by increasing the number of dispersed particles in the system. But most often the change is due to either temperature or the degree of alkalinity or acidity of the substance. One may take a thin colloidal solution of fine clay suspended in water and add clay until the mass becomes a semisolid gel. Many a mud pie made by children has depended on this change. The housewife boils sugar and fruit juices down to the proper degree of viscosity over the stove and then pours them into jelly molds and lets them cool. As the temperature falls, a point is reached at which the change from the sol to the gel condition takes place, and the result is a prized adjunct to the table menu. The solidifying of many desserts, such as puddings that contain cornstarch or gelatin preparations, depends on this principle for their change from the liquid to the colloidal solid state. Agar, used to make agar plates in bacteriological laboratories, furnishes another example.

Applications of Colloidal Chemistry. On the extensive surfaces presented by certain colloidal particles physical processes and chemical reactions take place with great facility. In some cases it is difficult, if not quite impossible, to say whether the charged surface acts as a physical agent or as a chemical agent in promoting chemical change.

In connection with the chemical changes promoted by colloids let us consider catalysts. If a smooth platinum plate is lowered into a solution of hydrogen peroxide (H_2O_2), practically no decomposition into water and oxygen results. However, if the plate is roughened before immersion, there is a slow evolution of oxygen. If the platinum plate is ground to powder first, there is an energetic chemical decomposition, and consequent liberation of oxygen. If the platinum is reduced to the fineness of the colloidal condition, the chemical decomposition may be so violent as to result in a sharp



Western Precipitation Corporation

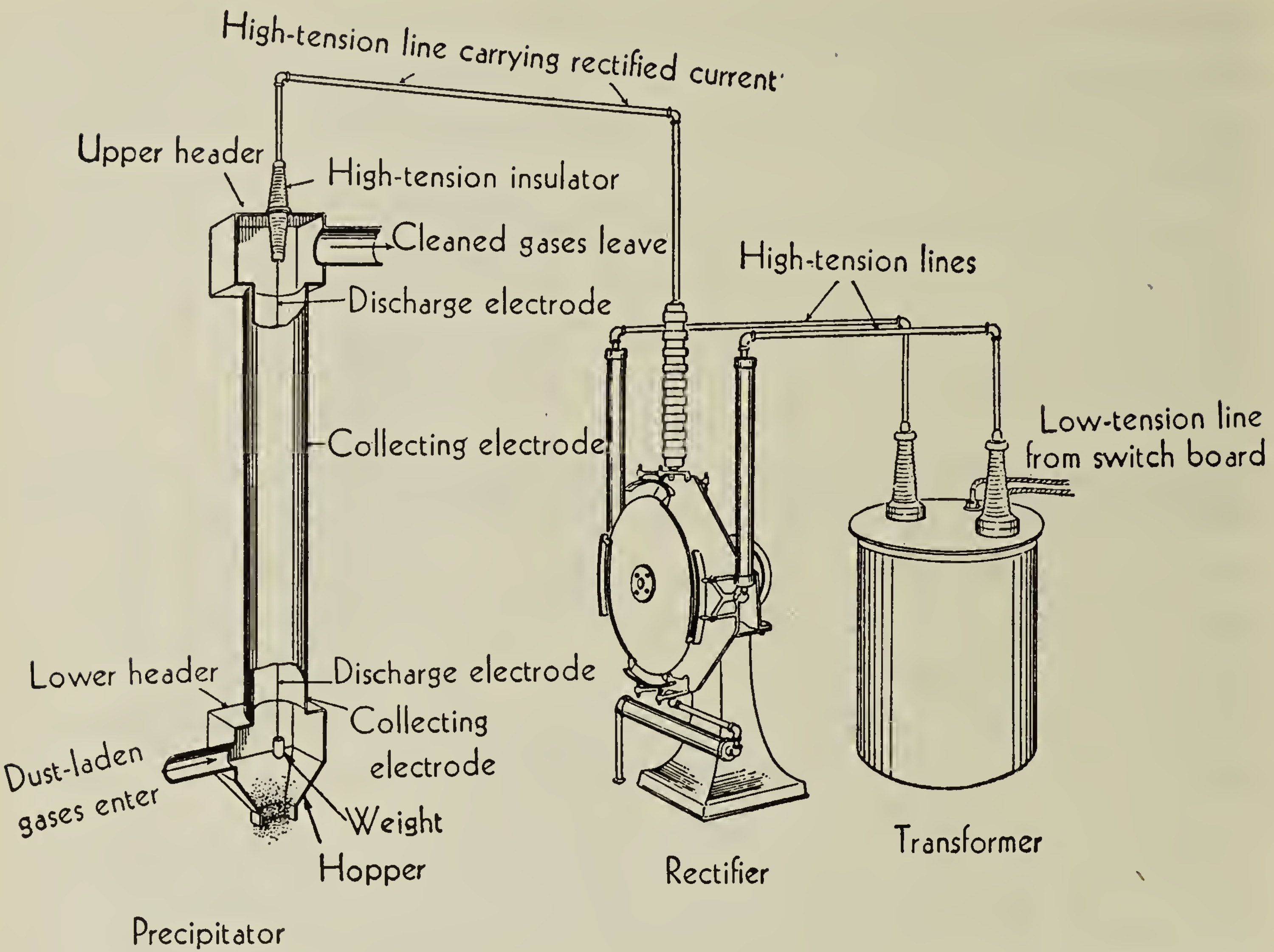
A Cottrell film-precipitator used to collect carbon from hydrogen gas explosion. In these wide differences of behavior the same factors, platinum and hydrogen peroxide, are present. The variation in results depends on the extent of the active surfaces presented as the size of the platinum particles is reduced.

An important practical application of colloidal chemistry is found in the precipitation of colloidal particles. One or two instances of this principle have already been referred to. The principle is applied in an invention by Frederick G. Cottrell, a noted American chemist, to abate the smoke nuisance in cities. Smoke is considered to be colloidal particles dispersed in a gaseous phase, the air. In this invention a highly charged wire (electrode) is passed down the center of the chimney. The wall of the chimney, being grounded, carries an opposite electric charge by induction. The smoke particles, already bearing a partial charge as they leave the furnace, are further charged and are driven by the force of the electrical field toward the walls of the chimney, where they collect as soot, or carbon black. Not only is the smoke nuisance reduced, but hundreds of tons of carbon black are thus obtained for use in the industries.

The fumes from furnaces of different kinds often carry valuable metals, such as gold, in the colloidal state, which may be precipitated in the same manner. In cement factories the ceilings are sometimes electrified to recover the cement dust which would otherwise be lost. In a cement plant at Riverside, California, the management was compelled to install a Cottrell precipitation apparatus in order to arrest the dust which would otherwise escape and settle on the leaves of the neighboring citrus-fruit groves. The coating of dust thus formed on the leaves interfered with normal photosynthesis. During a twelve-year period approximately 350,000 tons of dust were collected by the Cottrell precipitator.

A few years ago it was found possible to precipitate rubber particles from the crude latex, or "milk," obtained from rubber trees. In this way, by electrifying a metallic form of the hand, a rubber glove may be deposited about the form. Also, a firm rubber infiltration may take place into fibers placed about an electrified form in the same manner.

Smoke serves fruitgrowers in a different way. When frost is imminent in early spring, the citrus-fruit raisers of California, Florida, and other regions burn smudge pots in the orchards. The burning crude oil not only produces heat, but also emits clouds of black, sooty smoke. The colloidal smoke particles afford nuclei of condensation around which the moisture of the air condenses. These clouds serve as a "blanket" to prevent the radiation of heat from the earth. If the weather is not too severe, the temperature may be held above the


High-tension line carrying rectified current
Upper header
High-tension insulator
Cleaned gases leave
Discharge electrode
High-tension lines
Collecting electrode
Low-tension line from switch board
Lower header
Discharge electrode
Collecting electrode
Dust-laden gases enter
Weight
Hopper
Rectifier
Transformer
Precipitator

Western Precipitation Corporation

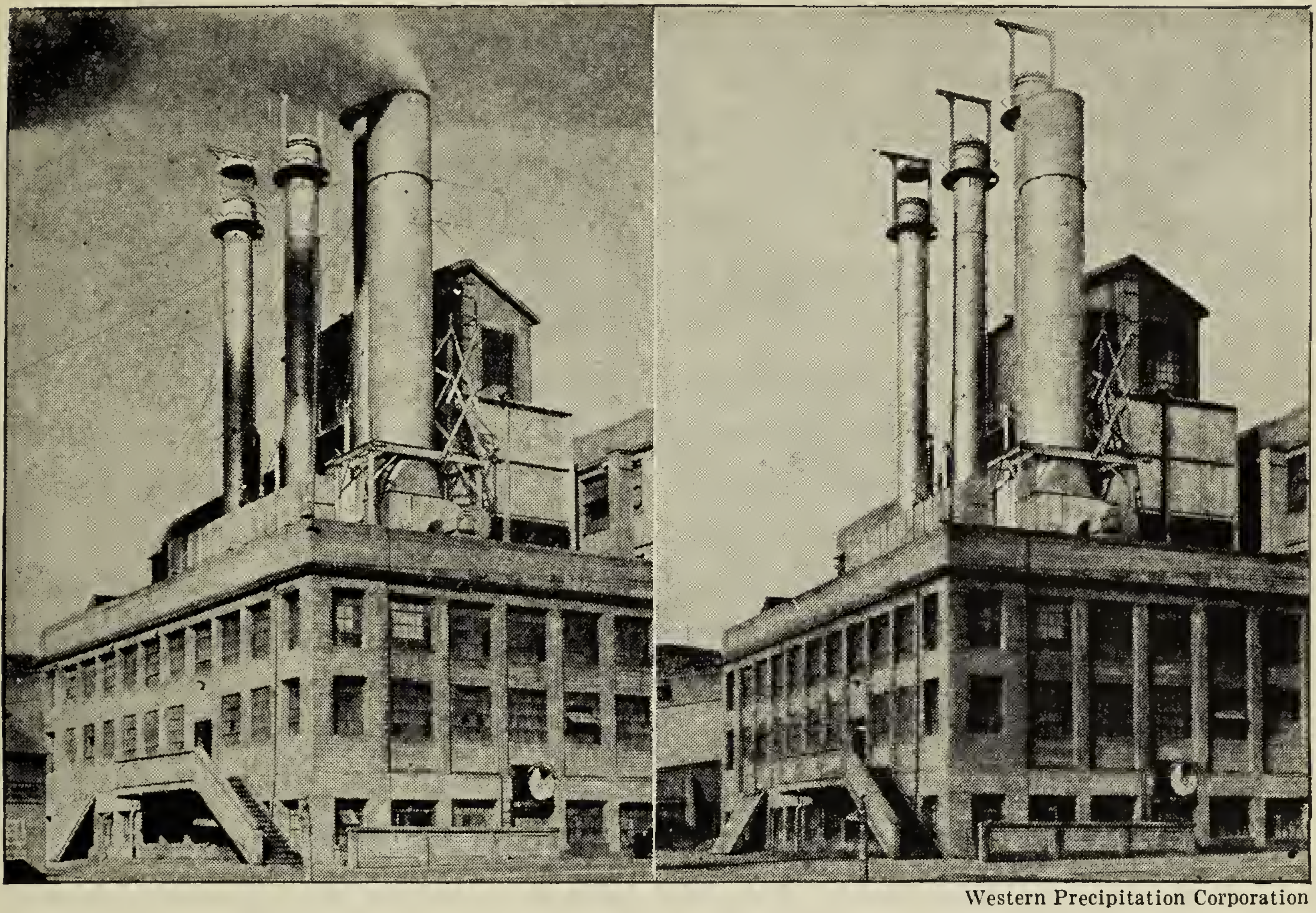
How the Cottrell precipitator collects carbon from smoke and dust from the air

freezing point, and the fruit crop may thus be saved. Apples and other fruits are often protected from frost in the same way.

Colloidal particles also exhibit the phenomenon of *adsorption.* Adsorption is a type of adhesion in which the particles of a substance tend to collect upon the surfaces of the particles of another substance by adhering to them. For instance, if a solution of litmus is permitted to pass through a filter of colloidal carbon particles of sufficient thickness, the liquid drains off in a perfectly clear state. The litmus particles have been removed by adhering to the carbon particles.

In sugar refineries tons of ground limestone are used as an adsorbent. The sugary juice is filtered through this medium, and the proteins and other organic impurities are held back by adsorption. Gas masks used as a protection against poisonous gases utilize this principle.

Old newspapers may be reclaimed for use by placing the ground paper in a suspension of bentonite, which is a fine volcanic ash. The carbon particles in the printer's ink are adsorbed to the bentonite, thus restoring the paper pulp to its original whiteness. This principle of adsorption is also employed in



Western Precipitation Corporation

A B

A Portland-cement plant with the Cottrell smoke-precipitator not in use (A) and in use (B)

the flotation process of metal-refining, especially when the ore is in the form of sulfides. The finely ground ore and silicates are mixed with water containing emulsified oil. The oil droplets adhere to the sulfide particles and serve like "life-preservers" to float the particles of ore to the top, where they can be taken off. The undesired silicates remain behind in the water. The adsorption and subsequent flotation are facilitated by passing a stream of air in the form of bubbles through the mixture to agitate it.

In recent years it has been found that frost injury to plants arises largely from the drying out of the cell proteins and the protoplasm. As the ice crystals form, the water is withdrawn from the protoplasm. Consequently the protein components of the cell "salt out," or coagulate, resulting in death. It has been found that frost-resistant varieties of crop and garden plants are those capable of forming a rich supply of hydrophylic (Greek *hydōr*, "water" + *philos*, "loving"), or "water-loving," colloids. These take up water so tightly by adsorption that the force of crystallization in freezing cannot pull it out of the living parts of the cell. Water in this condition is known as "bound water." Some hibernating animals, such as the chrysalid stage of butterflies and the cocoons of moths, are known to be protected against death from frost injury in a similar manner.

There are also colloids that act as protective agents, and for this reason are called *protective colloids.* Colloids that exhibit this character are of the emulsion type and "protect" by forming a coating about other colloidal particles which will not permit the latter to coalesce and settle out of solution. Cream globules do not, under ordinary conditions, coalesce into oil globules large enough to form butter. This is largely because each droplet is coated with a milk protein called casein. By agitating the cream mechanically in a churn this casein protective colloid can be rubbed off, and coalescence of the oil droplets into butter quickly follows.

Dirty locomotive boilers, when operating, often foam and throw water into the cylinders instead of dry steam. The result is a decided loss in power. When this dirt accumulates in the form of boiler scale, it must be washed out, which demands extra labor and causes loss of time. By using a boiler compound composed of a gluey substance the dirt particles become coated with this protective agent. In this way they are kept suspended and to a great extent may be blown out at the blowoff cock and thus save the time and inconvenience of washing the boiler.

Oily sprays are often used as insecticides. In these sprays the oil is in a highly emulsified state. To keep it in this condition some alkali, usually in the form of soap, or a casein is added to the spray, which serves as a protective colloid to prevent the oil droplets from coalescing and floating to the top. The same principle is operative in the use of soap as a cleansing agent. The soap not only emulsifies the grease but is believed to break up the particles of ordinary dirt and wrap itself about them to keep them in a state of colloidal suspension. In this condition the dirt particles may readily be washed away by the mechanical effects of water.

Gelatin is added to ice cream to make it smooth. It acts as a protection against the forming of larger ice crystals during freezing. Gallstones, under conditions of normal health, are prevented from forming by the protective colloidal action of the bile. If that fails, the poorly soluble cholesterol and bile salts precipitate to form stones that may cause serious pain and necessitate a surgical operation.

Questions for Study

1. How is organic chemistry distinguished from inorganic chemistry?
2. What discoveries reduced the gap between the older conceptions of organic and inorganic chemistry?

3. What are some of the common organic compounds that affect the daily life of the average man?

4. What scientific attitude is exemplified in man's changing ideas of the relation between organic and inorganic chemistry?

5. What are some of the aliphatic compounds that are prominently concerned in everyday experience?

6. Can you name some aromatic hydrocarbons that one often has experience with in everyday life?

7. How do colloidal solutions differ from true solutions?

8. Cite instances in your daily life in which colloids are involved.

9. Name some suspensoids and some emulsoids that occupy an important place in the life of the average person.

10. How does adsorption differ from absorption?

11. How is soap believed to act when cleansing either fabrics or the surface of the skin:

12. Why do the ingredients of mayonnaise dressing not separate under ordinary circumstances, while cream does separate from milk if left standing?

13. Why will very roily water not completely clarify when left undisturbed?

14. In fruit jelly what forms the disperse phase and what the dispersion phase?

15. In the smoke issuing from a chimney what forms the colloidal phases?

16. Why is a little soap usually added to the oil in forming a kerosene emulsion to be used as a spray?

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CHAPTER SIXTEEN

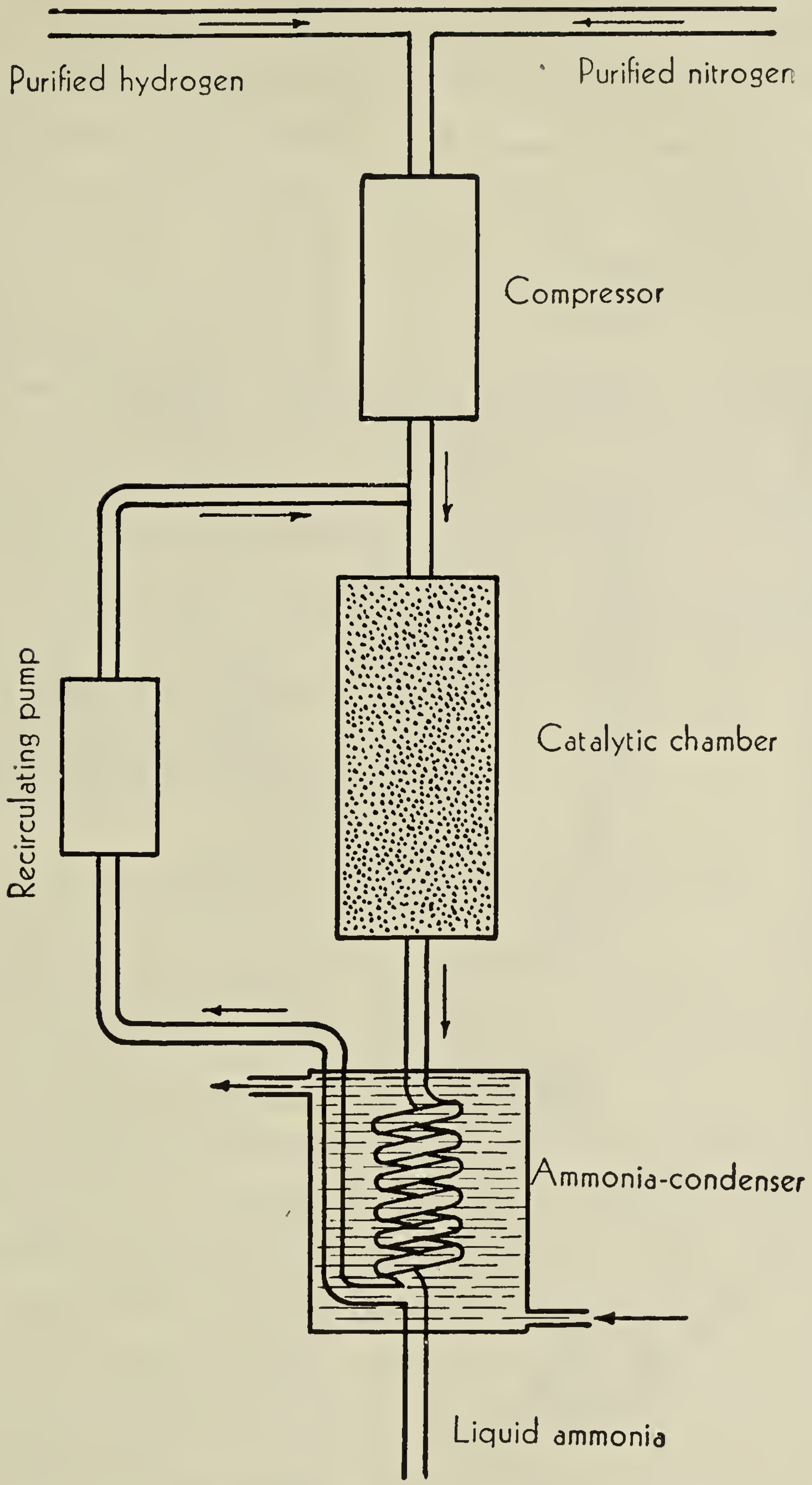
Chemical Products Have Added to the Convenience and Pleasure of Living

Nitrogen Fixation. Less than fifty years ago, aside from the nitrates stored in the soil by leguminous plants and their associated bacteria, man was dependent largely upon the deposits of Chile for his supply of sodium nitrate. The growing use of this salt for the manufacture of explosives and as an artificial fertilizer made heavy inroads on the known natural supply.

In 1905 Haber, a German chemist, discovered that under high pressure and suitable temperature nitrogen and hydrogen combine directly to form ammonia (NH_3). Later, about 1912, Bosch developed active catalysts to make the process a commercial success.

Never was a discovery more timely from the German point of view. For the first World War was just breaking, and Germany was forthwith cut off from the Chilean supply of nitrates. She was forced to fall back upon her own resources for a supply of this salt for the manufacture of explosives. Her ammonia factories were rushed to completion. The nitrogen used in this industry was usually obtained from liquid air and the hydrogen from water vapor, or steam. The ammonia produced by this process was then converted into nitric acid and the required nitrates. Had it not been for the discovery of these methods for the fixation of nitrogen, Germany would have been forced to surrender for the want of explosives long before she did. So even wars and the destinies of nations may depend upon chemistry.

Other processes of using atmospheric nitrogen in the production of nitrates for manufacturing and fertilizer requirements have been perfected. One of these is the Birkeland-Eyde process, which resembles lightning in its action. When a bolt of lightning passes through the air, some nitrogen is combined with oxygen, which by subsequent combinations gives nitrogen dioxide (NO_2). This gas combines with water to produce nitric acid (HNO_3). By producing powerful artificial electric discharges within drums through which a stream of air and water vapor is passing, nitric acid may be artificially produced. In general, however, the ammonia process has become much the more important. The production of synthetic nitrates replacing saltpeter from Chile had grown in the United States before the war from nothing to 185,000 tons annually. So there is now no dearth of these valuable nitrogen compounds, and the Chilean deposits have shrunk immeasurably as an economic factor in world affairs.


Purified hydrogen
Purified nitrogen
Compressor
Recirculating pump
Catalytic chamber
Ammonia-condenser
Liquid ammonia

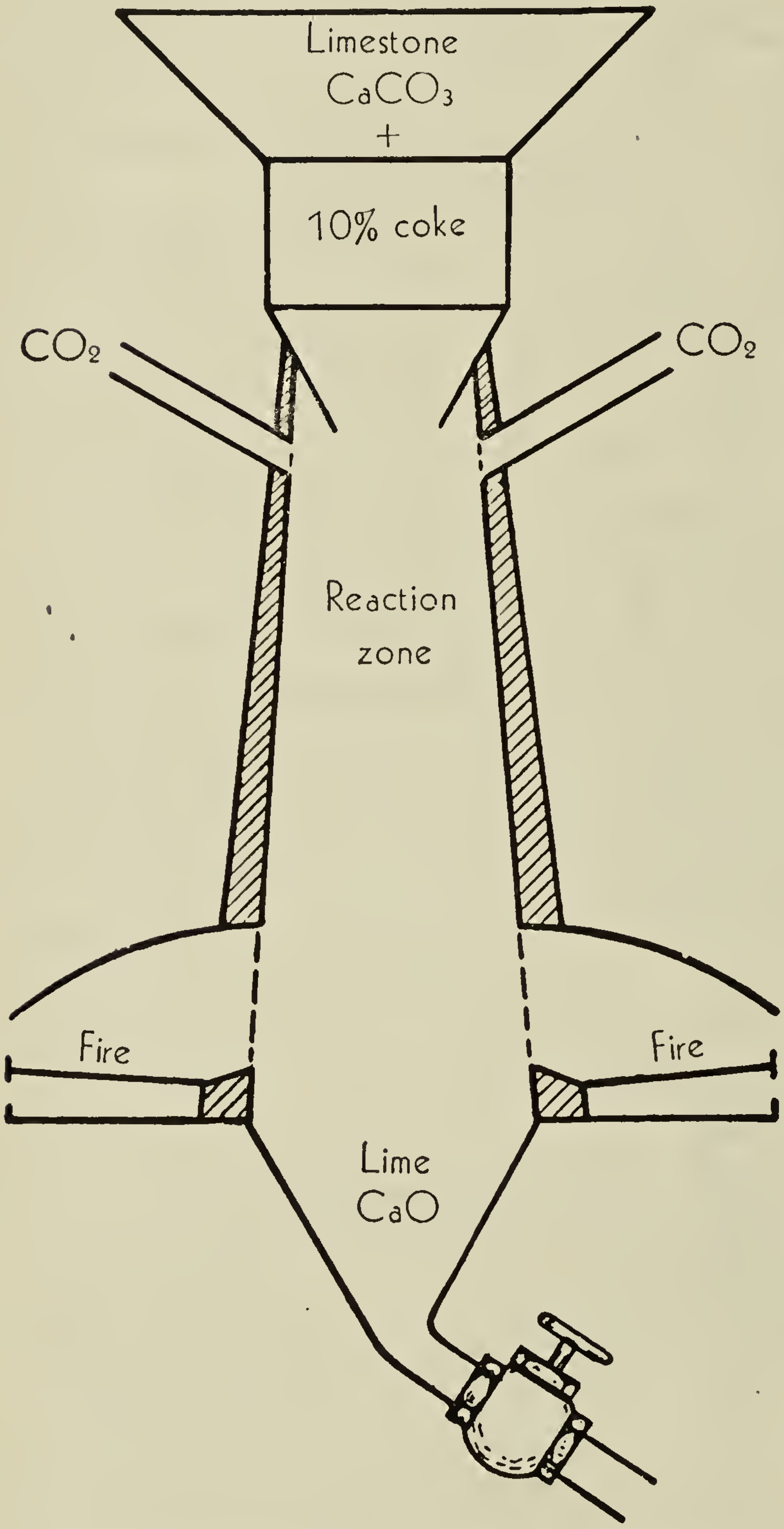
A diagram showing the principle developed by Haber to produce liquid ammonia

The hydrogen and nitrogen combine in the catalytic chamber

Lime. Lime (CaO), or quicklime as it is often called, is another compound used extensively. It is made from limestone, or calcium carbonate ($CaCO_3$). The limestone is heated to a temperature of a few hundred degrees in either vertical or rotary kilns. Under these conditions the carbonate molecule is broken down, giving off a gaseous carbon dioxide, with the solid calcium oxide remaining behind. Thus

$$CaCO_3 + \text{heat} \longrightarrow CaO + CO_2$$

Several million tons of quicklime are made in the United States annually, of which about one third goes into the building industry. Quicklime is slaked with water and mixed with sand and hair to form a mortar for plaster. The hair is added as a binder to help to prevent cracking when the green plaster is drying. The "setting" of mortar to become hard plaster depends not only upon its loss of water but also upon a reversal of the chemical change of slaking ($CaO + H_2O \longrightarrow (CaOH)_2$). Gradually the carbon dioxide of the air unites with the calcium hydroxide ($Ca(OH)_2$) formed in the plaster to produce calcium carbonate again.

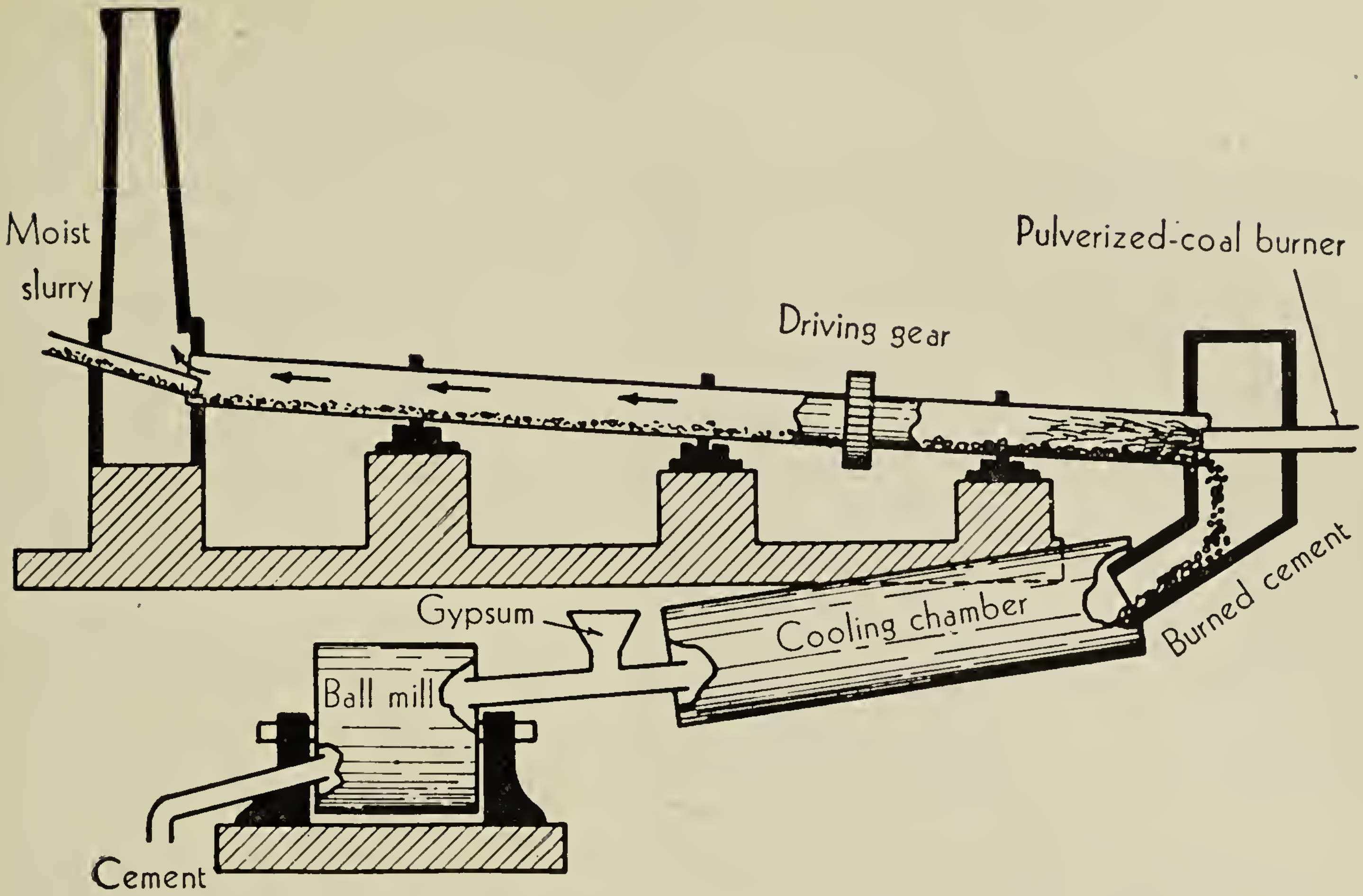


A diagrammatic cross section of a limekiln

Cement. It has been known for centuries that by heating limestone containing clay it is possible to produce a hydraulic cement, that is, a cement which, when mixed into mortar, is capable of setting under water. The exact chemistry involved in this setting process is not entirely understood. The ancient Romans seem to have been aware of this setting principle, however, and to have employed it in the materials used to build their famous aqueducts.

There are various kinds of cement, such as quick-setting cement, slow-setting cement, and waterproof cement (which when set is impervious to water). The kind used by far the most extensively in the United States is Portland cement. It is so called because of its resemblance in color to the famous stone quarried near Portland, England.

The process of manufacture varies, but essentially it consists in heating a ground mixture of limestone and clay together to a temperature just short of the melting point. A special type of clay is required which includes oxides



A diagrammatic cross section of a cement kiln

of silicon and aluminum in the desired proportions. By grinding, mixing with water, and then heating in a kiln the mass is reduced to the clinker form. The clinker is now ground to a very fine powder in rotating drums filled with steel balls and is usually mixed with from 2 to 3 per cent of gypsum ($CaSO_4$). The chemical proportions of the ingredients must be carefully controlled, and the grinding must be thorough. Seventy-eight per cent of the ground material must pass through a sieve having 40,000 openings per square inch. This product, when mixed with gravel and sand to form concrete, is used in construction, in tile-manufacturing, and in innumerable other ways. In fact, it is made use of in almost all branches of the building industry.

Glass. Ordinary glass, such as window glass, is made by fusing together at a high temperature sand (SiO_2), limestone ($CaCO_3$), the carbonate and sulfate of sodium (Na_2CO_3, Na_2SO_4), and some compound of aluminum. Various other ingredients are added, depending on the kind and character of the glass desired. Since there are many types of glass and the coloring techniques have been developed into a complex art, glassmaking has become highly technical. All glass, however, is made of these basic, fused ingredients; and such variations in treatment as are made are for the purpose of preparing the products for special purposes.

The making of glass is a very old craft. Both the Egyptians and the Phoenicians understood it. Egyptian glass vessels dating back to 1400 B.C.

have been unearthed, and it is thought that possibly these early master craftsmen discovered the art. If this view is correct, it serves as one more evidence to reinforce the conclusion reached by the illustrious Greek writer Herodotus. He wrote that Egypt "contains more wonders than any other land, and is pre-eminent above all other countries of the world for works which almost baffle description." From Egypt as a center the knowledge of glassmaking is believed to have been carried to the Assyrians, Phoenicians, and Greeks, all of whom were familiar with it. During the Middle Ages glassmaking of various kinds became a highly aesthetic art. Some of the most prized possessions from that period consist of highly colored and artistically fashioned vases and jars.

In modern times glassmaking of all types is not only connected with the fine arts, but has become a most important industry. Windows, bottles and glass vessels of all kinds, telescope lenses, windshields, floor tiling, and transparent or semitransparent building blocks are made of it. In 1929 the value of the output of the glass industry in the United States was well over $300,000,000. It is believed that glass is destined to occupy a still larger place in the construction industries.

The use of glass was greatly increased by the discovery of the art of glass-blowing. The glass-blower gathers a mass of semimolten glass at the end of a long metal tube and by skillful manipulation fashions it into the shape desired. Sometimes the semimolten mass is blown inside a hot mold to form a smoother, more uniform surface. Formerly window glass was made by blowing large cylindrical bubbles which were cut on one side and allowed to flatten in a heated furnace. Recently machinery has replaced hand labor, and glass sheets are now made by drawing the molten material between a series of rollers, where it is pressed into sheets of any thickness desired. Though the drawn-glass sheets are much smoother than the sheets made by "blowing," they too have on their surfaces irregularities which refract the rays of light as they pass through the glass. Almost any common windowpane will show this defect. To obviate this difficulty the sheets of glass may be polished mechanically on both surfaces to remove the irregularities that distort the light. A better quality of glass, made into somewhat thicker sheets, is polished mechanically and is known as polished plate glass. It is used for mirrors, display windows, and other purposes where clear, true, undistorted vision is desired.

Pyrex glass, much used in the making of cooking utensils, telescope mirrors, and other objects, is made of 80 per cent of silica and 12 per cent of boric oxide, with smaller amounts of sodium oxide and aluminum oxide. Its special value is chiefly that it expands less when heated than common glass.

This greatly reduces the danger of breakage. Most heat breakage in glass is caused by the unequal stresses set up as it expands or contracts. Hence the lower the coefficient of expansion, the less the likelihood of cracking.

Annealing is a treatment which greatly reduces the frangibility (breakableness) of glass. The cooling process in ordinary glass sets up many stresses which persist at the surface and beneath it. When a scratch is made on the surface, or the surface receives a sharp blow of any kind, the increased weakness or the force added to the tensions which already exist is likely to cause breakage. Annealing is carried on in annealing ovens. In these chambers the glass is reheated to near the softening point, and the cooling which follows is so regulated as to take place very slowly. This slow cooling largely eliminates the strains set up in the originally rapidly cooled glass.

Pittsburgh Plate Glass Company

Duplate safety glass is a safe place to land without being cut

The wide variety of hues and tints found in glass is due to the coloring agents added. The green tint found in the ordinary cheaper bottle and windowpane glass is caused mostly by the presence of iron oxide impurities. Red in glass arises from the addition of gold salts, copper oxide, or selenium compounds; amber and yellow are produced with the use of charcoal, uranium oxide, or cadmium sulfide; blue, with oxides of copper and cobalt; and violet, with manganese oxide.

Safety glass, now required by law in most states for use in the windows and windshields of automobiles, is a "sandwich" glass. The two outer plies are of good-quality plate glass, and the middle one is made of some tough, transparent plastic substance—for example, celluloid. This inner layer greatly reduces the danger of breakage in case of collision. The glass will shatter, but it will not break entirely so as to present sharp, cutting edges and rapier-like points.

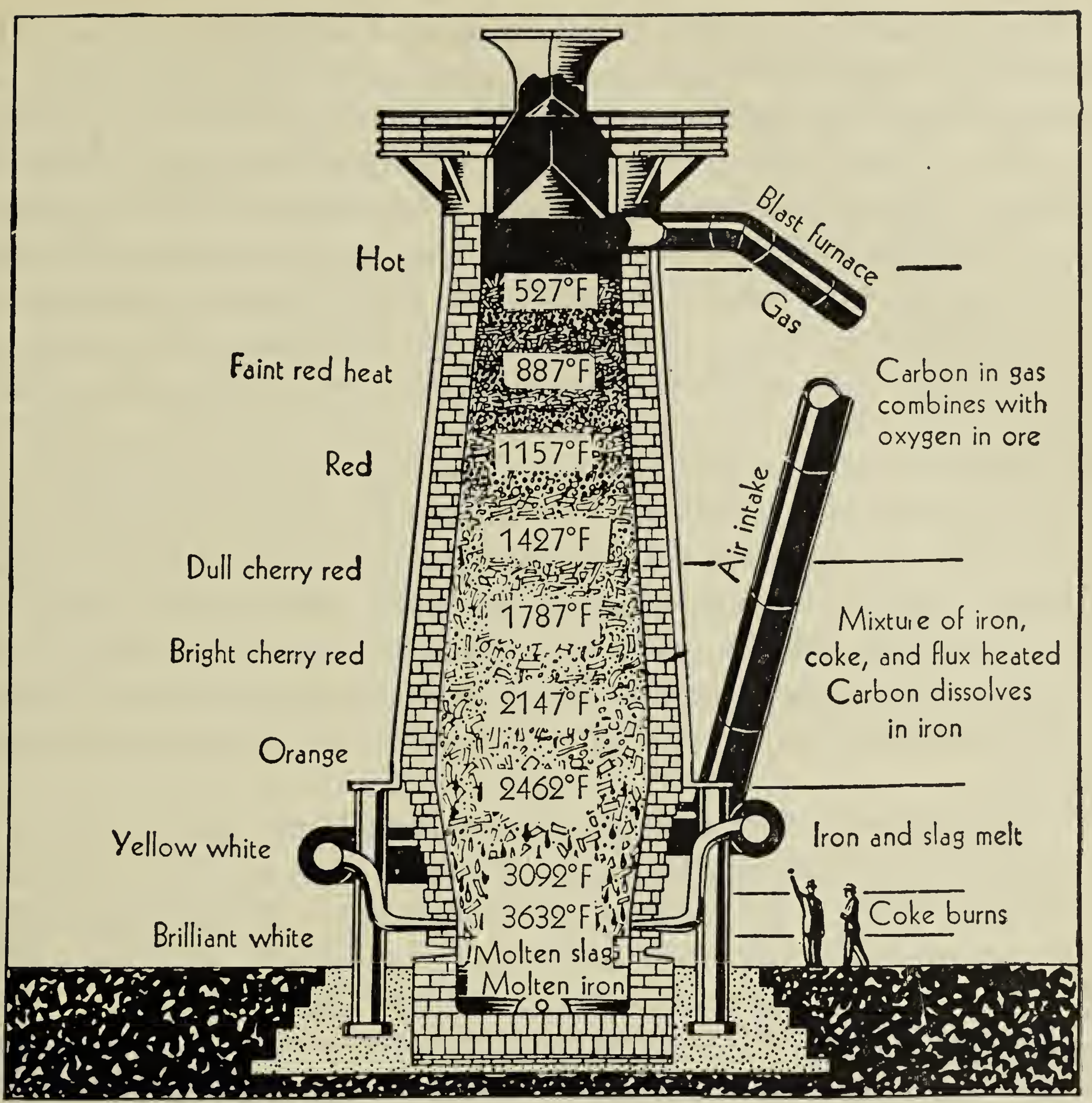
Metals. It is likely that primitive man's attention was first directed to the metals by small amounts of them which he found free in nature. Perhaps copper and gold were the first metals discovered in the uncombined state. Later, primitive man discovered that metals could be extracted from their ores. Metals separated fortuitously from the ore-bearing stones used to enclose his outdoor fire are believed to have led to this discovery.

After this advance had been made, man had at hand the tool for a new age. In fact, the two metals copper and iron have so molded the characteristics of industry since that discovery that subsequent human history has been divided into two divisions, the Bronze Age and the Iron Age. Today we are said by some to have entered the Steel Age. The statement may be true; but since steel is mostly iron, there seems little warrant for calling the present a new age.

Copper was probably the first metal used by man. In a short time he discovered that a small amount of tin could be mixed with copper to form the alloy bronze. This combination proved to be far superior to pure copper for general use. It was much harder and decidedly more resistant to the corrosive effects of the atmosphere. Both copper and bronze, however, were soon displaced when the more abundant and harder metal iron was discovered.

Iron is deposited as an ore in many regions of the earth. In this respect the United States has the most extensive known resources in the world. We were not the first people, however, to learn how to extract iron from its ores on a commercial scale. That came earlier than our industrial development. Had one visited the lower Rhine valley as early as the middle of the fourteenth century, he would have found there the Belgian blow oven in which the first pig iron in history was produced. This smelter was about sixteen feet high and burned charcoal for fuel. The air blast was furnished by a crude bellows pumped by water power. When in use, this blow oven operated on the same principle as our blast furnaces today. At proper intervals molten iron was drawn from the taphole at the bottom and permitted to flow into a large puddle with a number of smaller ones adjoining it. The whole resembled an old sow and her brood, from which the term *pig iron* arose.

Modern blast furnaces are from eighty to ninety feet in height and have a diameter at the widest point of twenty feet. The charge consists of the ore, flux, and coke (see figure on page 243). The flux is some material added for the purpose of purifying the molten metal and rendering the slag more liquid. The particular kind of flux used depends largely upon the kinds of impurities in the ore. The one commonly used is limestone. The coke is burned by a hot blast forced up through the charge.


Hot
Faint red heat
Red
Dull cherry red
Bright cherry red
Orange
Yellow white
Brilliant white
527°F
887°F
1157°F
1427°F
1787°F
2147°F
2462°F
3092°F
3632°F
Molten slag
Molten iron
Blast furnace Gas
Carbon in gas combines with oxygen in ore
Air intake
Mixtuie of iron, coke, and flux heated Carbon dissolves in iron
Iron and slag melt
Coke burns

General Motors Corporation

A cross-section diagram of a blast furnace

The chemistry of the blast furnace is varied and complex. Different chemical reactions take place at different levels. Near the top and farther away from the air blast, the iron oxides are reduced by the carbon monoxide (CO) from below to form iron and carbon dioxide (CO_2); near the middle, the quicklime formed from the limestone unites with the siliceous impurities in the ore to form slag; and at the lower level, where the air blast is heavy, vigorous oxidation is taking place in the form of a rapid combustion of the coke. The heavier molten iron now settles to the bottom of the furnace, where it may be drawn off. One of these huge furnaces will swallow up 800 tons of ore, 400 tons of coke, and 100 tons of limestone each twenty-four hours, besides consuming 1200 tons of air from the hot-blast pipes. In this period 600 tons of pig iron, 500 tons of slag, and 1400 tons of gases will be produced.

Copper as an ore is frequently found combined with sulfur and iron. The blast furnace figures in its reduction, as in the case of iron, except that the process is longer and more complicated. The object is to free the copper from the sulfur and iron which accompany it. In the end impure copper blocks are obtained, which are comparable to pig iron. These blocks are further purified by electroplating. Here the copper block is gradually decomposed by electrolysis, and the pure metal is deposited at the negative pole as a refined plate.

Zinc is recovered from its simpler ores by the use of large retorts (a special type of furnace). It usually occurs as a sulfide or oxide, although not infrequently it is combined with other elements. The principle of the retort is that the sulfur or oxygen combines with other substances placed in the retort, such as anthracite or coke. Unlike the blast furnaces the retorts are heated externally. When a temperature of about 1100° C is reached, the sulfur or oxygen combines with other components, such as carbon, while the zinc vaporizes. Each retort is fitted with a condenser, which collects and reduces the metallic vapor into molten zinc. This may be withdrawn and cast into slabs. Further purification is accomplished by electrolysis, as in the case of copper, or by other methods.

Aluminum is the third most abundant element in the earth's crust. It is exceeded in abundance only by oxygen and silicon. As a metal it is only about one-third as heavy as steel or brass, reflects light rays well, is soft and ductile, and ranks third as an electrical conductor. This last quality, together with its abundance, has brought it into favor as a metal for the making of electrical transmission lines.

The man in America who solved the problem of producing metallic aluminum from its compounds at a cost which permits its general use was Charles Martin Hall, who was a student at Oberlin College. Many well-trained scientists had tried it before him but failed. However, Hall discovered in 1886 that melted cryolite (an ore of aluminum) will fuse the aluminum oxide bauxite, which is the most abundant source of aluminum. The fusion of the bauxite had previously been the great problem. Once melting is accomplished, the aluminum can be separated by electrolysis from its impurities and deposited in pure form. Special conditions had to be provided; but when they were worked out, the commercial production of aluminum was on a sound basis. Because of war needs the production of metallic aluminum has been stepped up to an estimated 2,100,000,000 pounds in the United States for 1943.

Aluminum is the principal element in clay, but no satisfactory and inexpensive way has yet been found for its extraction from this substance. Heavy deposits of alunite, an aluminum ore, have been discovered in the

Western states, particularly in Utah. The extraction of aluminum from this ore is a complicated process, requiring a very high temperature. It has been estimated that these deposits can be made to yield 100 tons of pig aluminum daily for a period of ten years.

Closely related to aluminum is magnesium, which is rapidly becoming important as a fabricating metal. One of the largest manufacturers of vacuum sweepers now advertises the framework of its appliance as being made of magnesium. This metal, like aluminum, is light, strong, and durable. It is, in fact, the lightest metal having the necessary durability for structural purposes.

Magnesium does not occur as a free metal in nature but is found in the form of a metallic salt. It is a constituent of many mineral waters, as well as the waters of the sea. The commercial source in the United States previous to the second World War was chiefly Michigan brine, which contains a considerable percentage of magnesium chloride. Owing to the heavy demand for this metal for the fabrication of airplane parts, industrial plants have been subsidized by the Federal government at a cost of millions of dollars to extract magnesium from its ores, such as magnesium carbonate.

Certain magnesium salts are used extensively for medicinal purposes. The carbonate ($MgCO_3$) and the oxide (MgO) are employed as antiacids to combat hyperacidity of the stomach. The former is also used as a cosmetic. The milk of magnesia sold as a neutralizer of gastric acid is a suspension of magnesium hydroxide ($Mg(OH)_2$) in water. The sulfate ($MgSO_4$) is popularly known as Epsom salts and is a very active cathartic.

There are many other valuable metals, including the precious metals gold, silver, and platinum. The discussion given here, however, will suffice to show the great importance of chemistry in separating metals from their ores and something of the methods by which this is accomplished.

Alloys of Metals. In the previous section certain representative metals and their extraction from different ores have been considered. In the pure state they are important, but not nearly so important industrially as when mixed with other substances to form alloys.

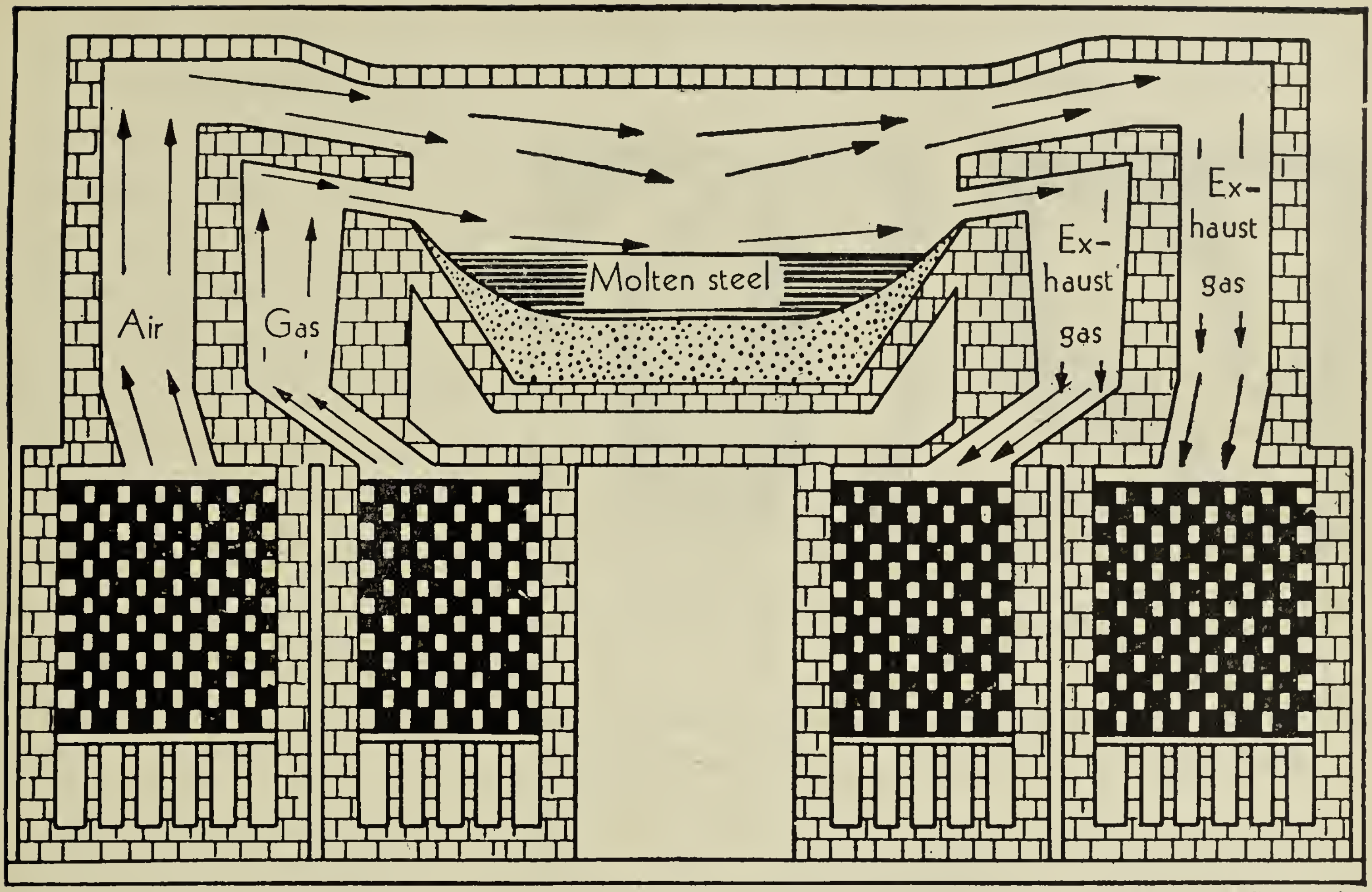
The chemistry of alloys is a complex matter. But the properties of the alloys are markedly different from those of any of the compounding metals taken alone. Steel, for example, is harder, more elastic, and finer-grained, and possesses a higher resistance to corrosion than common iron. When iron is alloyed with manganese, it is tough as well as hard and is used for grinding-machines, safes, and the jaws of rock-crushers. Silicon with iron gives special magnetic properties suitable for special parts of electric motors and electric generators. Silicon likewise increases resistance to corrosion. Chromium greatly decreases corrosive action in other metals. This property alone has brought chromium steel forward as an alloy to an almost astounding degree in recent years; and the end is not yet. This metal also when added to iron imparts a fine, smooth hardness and the alloy is employed in the making of cutting tools, files, and the faces of projectiles. Nickel in steel greatly increases its hardness, and such steel is used for automobile crankshafts and gears, where decided resistance to wear is desired. Invar is a steel alloy containing 36 per cent of nickel. It has a remarkably low coefficient of expansion when heated, and for this reason it is used in making measuring tapes and instrument scales. Practically all the nickel used in the United States comes from Canada, which has the richest and most productive mines of this metal in the world. In 1939, a year whose economies were not greatly deranged because of war activities, we imported from our northern neighbor about 99 per cent of all the nickel used in our manufacturing enterprises, or approximately 47,000,000 pounds of metallic nickel, its ores, and concentrated compounds. Cerium forms another valuable alloy of iron. Steel containing 70 per cent of this metal emits a spark when struck; hence its use in cigar-lighters.

The science of producing alloys is not a new one. To some degree the ancients understood it. Bronze, an alloy of copper and tin, was made early and was put to many uses, as it still is today. Pliny, near the end of the first century of the Christian Era, wrote that making alloys, which was "formerly done for the sake of reputation, is now undertaken for the mere purpose of gain—men of rank in all countries endeavor to acquire fame by the practice of it."

The degree to which the art of alloy-making was practiced in those far-away days, however, was very small compared with the degree to which it is practiced today. With the ancients it was an art; with modern metallurgists the development of chemistry has made it a highly technical science.

Iron Alloys. There are many iron alloys, but steel is the most important one. To convert iron into steel it is necessary to remove from the metal most of its impurities, especially sulfur and phosphorus, and then to add small amounts of other ingredients to produce the kind of steel desired. The removal of impurities is usually accomplished in a Bessemer converter or an open-hearth furnace, after which the molten metal is treated with other components necessary to form the alloy.

Carbon is the most common element alloyed with iron to form steel. This crucible steel, as it is called, contains but from 0.75 to 1.5 per cent of carbon. Nevertheless, the addition of this small amount of carbon makes the



General Motors Corporation

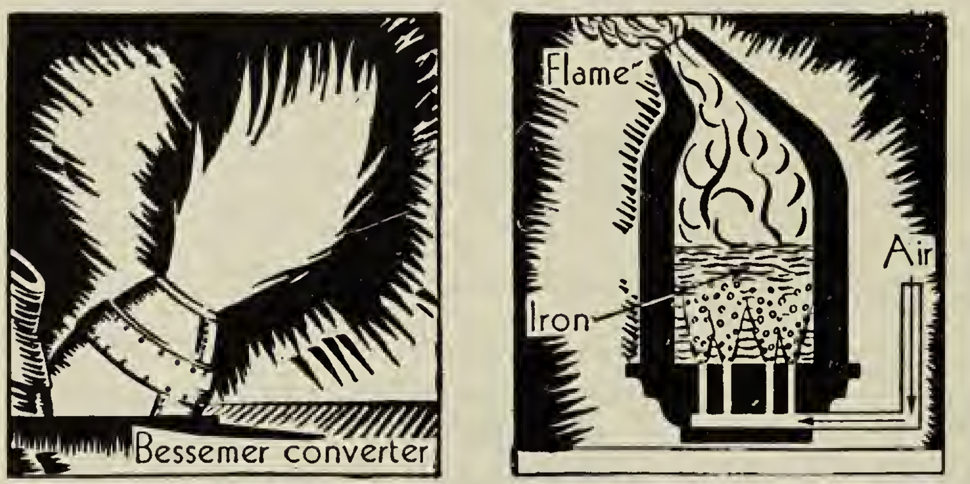
An open-hearth furnace, used to produce steel

chief difference between hard, elastic steel and soft, tough, ductile wrought iron. Crucible steel is used for watch springs, razors, knives, and other articles requiring elasticity and a keen cutting edge.

Other steel alloys are formed by adding to wrought iron small amounts of such substances as vanadium, silicon, manganese, chromium, tungsten, nickel, and molybdenum. The steel alloys are very numerous, with each possessing some quality which fits it for a particular use. Railway locomotives and cars, parts of automobiles and airplanes, tool dies for pressing sheet iron into shape, tool steel for the cutting edge of industrial tools, hard rollers for pressing white-hot bars of other steel into railroad rails, and tools and implements for hundreds of other purposes are made from steel. It has been said that the use of strong, resilient steel instead of iron has made it possible to reduce the weight of the automobile by half a ton.

An exhibit at the World's Fair in New York in 1939 showed two bars of steel. Each bar was $\frac{1}{8}$ inch thick and $\frac{7}{8}$ inch wide. The bar of ordinary steel weighed 151.5 pounds and supported as its maximum load a block of stone weighing 3717 pounds. Beside it the bar of high tensile steel, weighing only 43.5 pounds, supported a block weighing 12,880 pounds.

Non-Ferrous Alloys. Alloys of aluminum have become very important as construction materials in industry because of their light weight. These alloys are usually formed by combining aluminum with copper, silicon, nickel, and zinc. Alloys of aluminum and magnesium are particularly important.



General Motors Corporation

The Bessemer converter, in which iron is made into steel

Aluminum pistons, now used in most internal-combustion engines, such as the automobile motor, are made from this metal alloyed with copper and silicon. Until recently aluminum wire, rods, foil, sheets, and tubes were made from the pure metal. Now they are usually an alloy of aluminum and magnesium, which is harder and stronger.

One alloy of aluminum has proved especially valuable. It is composed of aluminum to which about 4 per cent of copper, 0.5 per cent of magnesium, and 0.5 per cent of manganese have been added. It is known by the trade name of Duralumin. When first formed, it was almost as soft as pure aluminum. But when it was heated to 900° F, quenched in water, and allowed to "age" at room temperature for four or five days, it gradually took on the strength of mild steel. More recently silicon has been added to this alloy as another ingredient, which greatly improves it. This alloy is used to make parts of airplanes, automobiles, and other machines in which great strength and reduced weight are desired.

Alloys of aluminum and magnesium are coming into rapid favor. This combination seems to be in the infancy of its utility. Each of these metals alone has a tensile strength (resistance to breakage) of about 13,000 pounds, which is very low. Their Brinell hardness (scale used to express the degree of hardness) is 26 and 30, respectively. But when the two metals are combined to form a certain alloy, the tensile strength of the product rises to 68,000 pounds and its Brinell hardness to 116. In other words, the alloy is five times as strong and almost four times as hard as either of its components.

The Federal Bureau of Mines has recently been carrying on some interesting experiments with alloys of manganese. For instance, an alloy of this metal and copper, when properly treated by heating, is as strong as steel but as noiseless and free from clatter as rubber. The chief engineer of the metallurgical division of the bureau, in a demonstration, dropped a piece of steel and one of brass on the floor with the usual clang. Then he dropped a piece of the new alloy. There followed a slight thump, much as if a piece of hard rubber had been dropped, but there was no metallic ring. This new product dampens, or absorbs, vibrations much like rubber or a good grade of cardboard. With this remarkable property added to the strength and elasticity of mild steel, if the alloy should be found to fulfill its present promise, it could be employed to eliminate the noise and clatter of spring suspensions, mechanical gears, and other metallic contacts of various sorts.

Manganese to which 2 per cent of copper and 1 per cent of nickel have been added results in a substance which resembles copper in its ductility and other qualities but which by heat treatment can be given an electrical resistance 1000 times that of copper. Such an alloy could well prove of great value in the manufacture of thermal electric appliances. Other manganese-copper-nickel alloys are reported to have such a tremendous hardening range as to make possible a tool tempered with a very hard surface and a soft, tough interior. Still another property of some of the new manganese alloys is high resistance to heat conductivity, which may make possible pot-holders, iron handles, and stove lifters made of this metal.

There are hundreds of other valuable alloys. Brass is a familiar alloy of copper and zinc, although other ingredients, such as lead and tin, are often added to give the product certain desired qualities. This substance is commercially the most important alloy of copper, and its composition runs about 75 per cent copper and 25 per cent zinc. It is used in the manufacture of jewelry, heavy machine bearings, automobiles, lamp fixtures, ammunition, clocks, and a large variety of other articles.

Gun metal, one of the alloys made of copper and tin, resists corrosion. The highly advertised and widely used monel metal for the more expensive sinks and other kitchen fixtures is an alloy of copper and nickel in the proportion of about 32 per cent of copper and 68 per cent of nickel. Common solder is a combination of lead and tin; and type metal, without which this book could not have been printed or the daily newspaper issued, is made chiefly of lead, tin, and antimony.

Wood's metal, made of lead, bismuth, tin, and cadmium, fuses at a low temperature and is used in electrical fuses and in sprinkling systems for fire protection. Babbitt metal, an alloy of tin, copper, and antimony, is soft and smooth, and does not heat easily under friction. For this reason it is used extensively as a lining for boxings that carry heavy machine journals as they rotate. The utility of alloys is apparently just in its infancy. So fast are new alloys being developed, and so rapidly is their use expanding, that "the Age of Alloys" may prove to be a suitable designation for the years immediately ahead.

Huge pile of sugar beets ready for shipment to the factory

This pile contains approximately 99,000 tons, which should produce about 250,000 hundred-pound bags of sugar

Organic Compounds Are of Inestimable Value to Man. When one turns to organic compounds of value to man, he finds a field as important as that of inorganic chemistry. If one were to attempt to enumerate without discussion all the carbon compounds in this category, he would find himself face to face with an almost inexhaustible task. The substances containing carbon, as we have found, are almost legion. In fact, almost every branch of industry is concerned in one way or another with chemical processes involving carbon.

Carbohydrates. Carbohydrates are so called because most of the natural forms produced by plants are composed of carbon plus the elements hydrogen and oxygen in the same proportion that the latter are found in water, namely, twice as many hydrogen as oxygen atoms. Glucose ($C_6H_{12}O_6$), sucrose, or cane sugar ($C_{12}H_{22}O_{11}$), and starch $(C_6H_{10}O_5)_n$ are familiar examples. These foods, as well as many other similar ones, are produced on a large scale by green plants only and are made from carbon dioxide and water. Sunlight furnishes the energy for the chemical processes involved.

Carbohydrates are of special value to man and other living things because they serve as energy-producing foods themselves and also as a basis for the elaboration of all other foods, such as fats and proteins.

Sugars are produced in great quantities by sugar beets and sugar cane. The world's consumption of cane sugar (sucrose) alone is estimated at 22,000,000 tons per year. Starch, of course, is consumed by man and animals in much larger quantities. So in carbohydrates we find the basic energy foods of the world.

Petroleum Products. Petroleum is a thick, viscous, greenish to brown or black oil. Chemically it is a complex liquid containing many hydrocarbons in solution in one another. These compounds have different boiling points, which fact makes it possible to remove the more volatile ones by the application of heat. Petroleum is believed to have been formed from the cellulose and oily portions of prehistorically submerged plant and animal remains. In the refining of petroleum, after treatment to remove the undesirable sulfur compounds, the crude oil is distilled to separate the valuable hydrocarbons. As a result, gasoline, kerosene, fuel oil, lubricating oils, vaseline, and paraffin (see page 220) are formed.

In the early days of the petroleum industry kerosene was the chief derivative. With the invention of the internal-combustion engine, which made gasoline-driven motors possible, a great demand arose for the lighter, more volatile gasoline. The volume of gasoline obtained by distillation soon became entirely inadequate to supply the demand. Consequently the petroleum chemists sought for some way of treating the heavier, oily derivatives of petroleum for the purpose of getting a higher yield of gasoline. This was achieved through a process called cracking. There are various ways of cracking the heavier oils, but the essential conditions are a high temperature and pressure. After this treatment, when the pressure is reduced, the more volatile gasoline passes off as a vapor, which is separated from the heavier residues and condensed to the liquid condition.

The results of research on methods of refining crude oil have increased the yield of gasoline from about 6 gallons per barrel of crude petroleum twenty-five years ago to approximately 19 gallons per barrel today. Under the best experimentally controlled conditions as many as 46 gallons of gasoline have been obtained from a single barrel of the crude oil as it came from the producing wells. So great has the demand for the lighter motor fuels become that in 1929, just before the world depression, the United States alone produced about 444,000,000 barrels of gasoline. This was about 190 gallons for every man, woman, and child in the country.

Coal is another source of gasoline production. The gasoline is obtained through a hydrogenation process by means of which a large portion of the coal is converted into oil. The Bergius method of gasoline manufacture has been used most extensively in Germany, where the need for supplementary power fuels has been greatest, particularly in time of war.

Dyes. One of the most important achievements of organic chemistry has been finding out how various kinds of complex molecules are built up. The result has been a knowledge of drugs, dyes, and perfumes of almost incalculable value. Formerly, for instance, man had to depend very largely upon plant and animal sources for his most prized dyes. Indigo was obtained from

Continental Oil Company

Petroleum refinery and tank farm

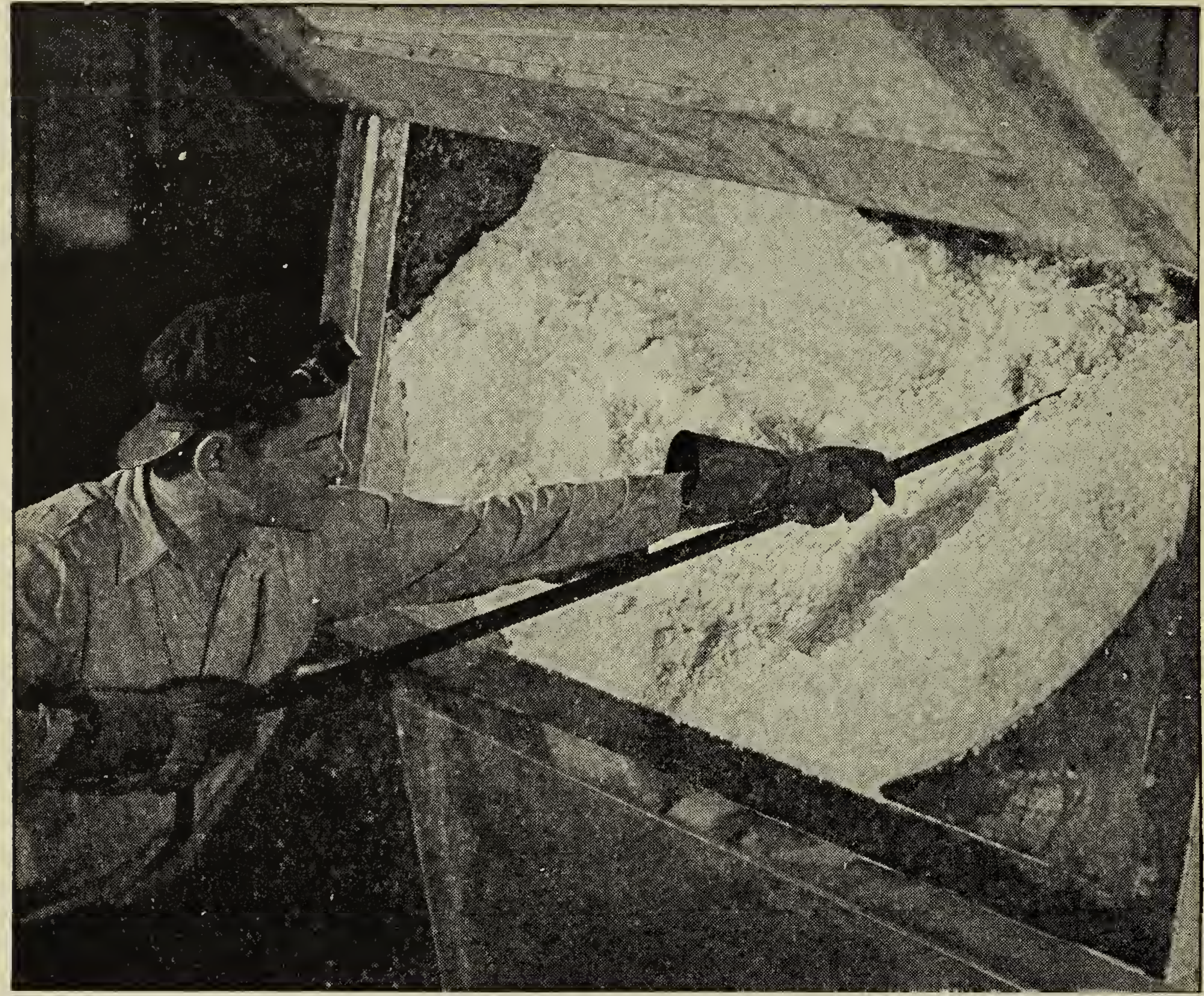
the indigo plant, red alizarin from the madder, red coloring from the saf- flower, scarlet from the Mexican cochineal, royal purple from Mediterranean shellfish, and litmus from lichens. Some of these dyes are used yet. But since the discovery by chemists that a whole array of dyes can be made from coal-tar products, the derivation of dyes from natural sources has been greatly reduced. Indigo furnishes an example. Some fifty years ago chemists went to work to determine the structure of this compound. By careful analysis of the decomposition products produced by heat and chemicals and by piecing together the knowledge thus gained, they were able to settle the question as to the molecular structure of indigo.

With this information chemists began to work on the task of making indigo molecules. It was a long, tedious one; but at length, beginning with benzene, the chemists were successful. As a result, we have all the indigo we can use today at a much reduced cost. Moreover, the synthesized indigo is better because it is chemically pure.

Today thousands of organic dyes of all colors and shades are derived from coal tar. This tar is essentially a by-product of the steel industry. When coal is heated to produce coke for the blast furnaces, about 6 per cent of tar comes off as a distillation product. This tar contains coal-tar crudes, from which the dyes are derived. At the outset of the artificial dye industry the products were obtained entirely from coal tar. But today many dyes which have no relation whatever to this coal distillate are synthesized. It is now possible to outline complicated synthetic processes in advance and to build up step by step a new substance whose dyeing properties can be foretold. Almost any color imaginable can be duplicated in the laboratory. One eminent authority states that these dyes "are almost infinite in the variety of their colors. The best of them are more brilliant than the natural dyes of similar hues and are much more permanent." So rapidly has production risen since the first World War that the figure of our annual output is now in the neighborhood of 122,000,000 pounds.

Rayon and Other Fabrics. When man became pastoral and agricultural in his habits, he greatly extended the possibilities of bodily comfort and protection. Wool, cotton, flax, and other fibers were called into use; and in their utility not only was bodily comfort greatly promoted, but ample opportunity was afforded for artistic expression.

In these modern days, when national self-sufficiency is being emphasized, chemists have succeeded in producing artificial fibers of great variety and exceptional service. Silk produced by domesticated silkworms has long been an expensive and prized fiber. The amount of it producible from the cocoons of



E. I. du Pont de Nemours & Company

Unloading the shredded chemically treated spruce-wood pulp used in the manufacture of Cellophane and rayon fabric

these insects, however, is comparatively limited and thus expensive. Because of this fact it is produced in greatest quantities by Oriental peoples, among whom cheap labor may be obtained.

As long ago as the seventeenth century threads resembling silk were being sold in England, but the first real silklike filaments prepared from nitrocellulose were produced in 1883 by the Englishman Swan. The most important technique of producing artificial silk from cellulose today is the viscose process, devised by Cross and Bevan in 1893.

Essentially this process consists in treating pure cellulose, usually obtained from wood pulp and cotton linters, with a strong caustic soda (NaOH) solution, which is followed with carbon disulfide (CS_2). By the action of these reagents the cellulose fibers are more or less separated and the whole slowly converted into a gelatinous mass. This product will dissolve in water or dilute caustic soda to form a thick, sirupy solution. This solution under pressure is

E. I. du Pont de Nemours & Company

When the chemical treatment of the Cellophane sheet is finished, the excess liquids are squeezed out by a series of rollers

then formed into fine threads a few thousandths of an inch in diameter by forcing it through small nozzles. By further treatment the threads are hardened into a product very similar to the original cellulose, except that the fibers are much more glossy and silky in character and appearance.

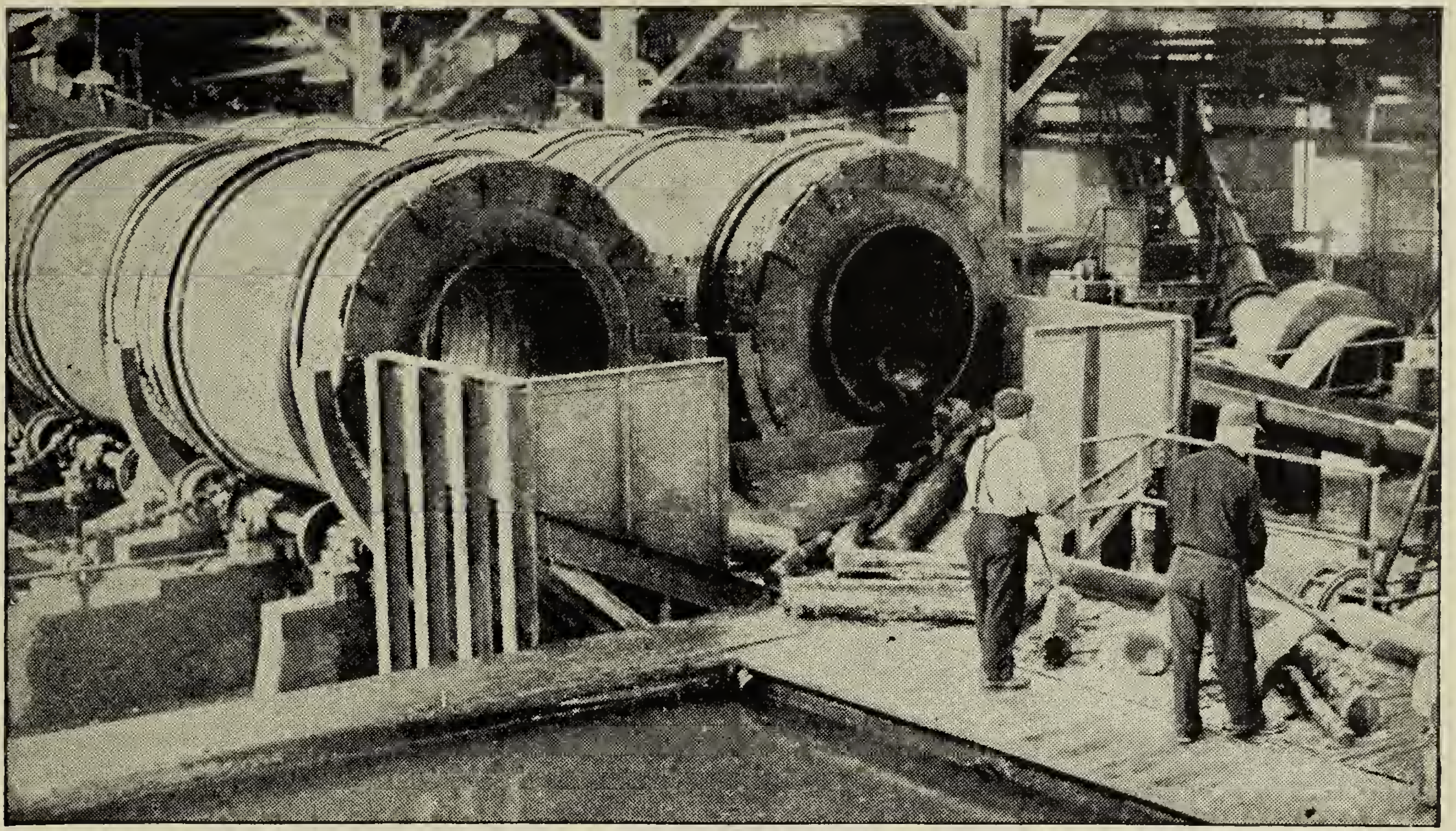
Viscose in the form of thin transparent sheets is also used as a wrapping for cigars, candy, dried fruits, and other foods. Recently a raincoat has been fabricated from it which is so light and of such small bulk that it may be folded and carried either in a pocket or a handbag. Sheets of this material are sold under the trade name Cellophane, and its use is constantly expanding. Today millions of dollars are invested in viscose and other rayon manufacturing plants, and the output, value, and uses of the products are constantly mounting. Just recently one of our largest chemical companies took out a patent for an artificial silk whose fiber is as strong as real silk, or stronger, has a beautiful glossy sheen, and is almost completely insensitive to moisture.

Nitrogen-Containing Textiles. For several years one of the large chemical-manufacturing companies had been experimenting in an attempt to discover a stronger, better-wearing fiber than rayon. After several years of experimentation in which the scientific obstacles to be overcome at times seemed almost insurmountable, success crowned the efforts of the experimenters. The result was a product sold under the trade name of Nylon. This substance is officially defined as "a man-made, protein-like, chemical product—which may be formed into fibers, bristles, sheets, and other forms which are characterized, when drawn, by extreme toughness, elasticity, and strength." It is already in great favor as a tough, stiff, long-wearing substance for the manufacture of toothbrush bristles.

Nylon differs from the rayons in that it is, as its definition makes clear, a protein product. This means that it has somewhat the same chemical composition as the proteins found in hair, silk, and wool. Chemically, however, Nylon does not have an exact counterpart in nature; so the fibers made from it are not only new in chemical composition but different from any existing product of either plants or animals. There are several varieties of Nylon, but the original materials from which the particular one used for textile yarns is made are coal, air, and water.

Nylon textiles are not damaged by water, nor are they injured by any of the liquid preparations commonly used as dry-cleaning agents. They are proof against both moths and fungi and undergo no appreciable deterioration when exposed to light. For this reason they may be stored for long periods without injury. Nylon is a good electrical nonconductor, and experiments are now in progress looking toward its use as an insulating material for various types of electric machinery and apparatus. Among the other possible uses for which Nylon is believed to be especially well adapted are woven dress goods, lace, bathing suits, underwear, and upholstery material. Nylon fish-lines are now on the market.

In the United States and in certain foreign countries a synthetic wool-like fiber has been made from the casein of cow's milk. About 6.6 pounds of this product can be obtained from 26 gallons of milk, and a pound of the synthetic fiber can be made from each pound of the dry casein. One factory in the United States just before the war was operating on an annual production schedule of 5,000,000 pounds of this artificial wool. The new fiber is less expensive than wool and fur and is said to blend well with other textile fibers. Cloth made from this material has attractive draping qualities. As a special war economy these fibers are now being used as a substitute for part of the rabbit fur used in the manufacture of felt hats.



Great Northern Paper Company

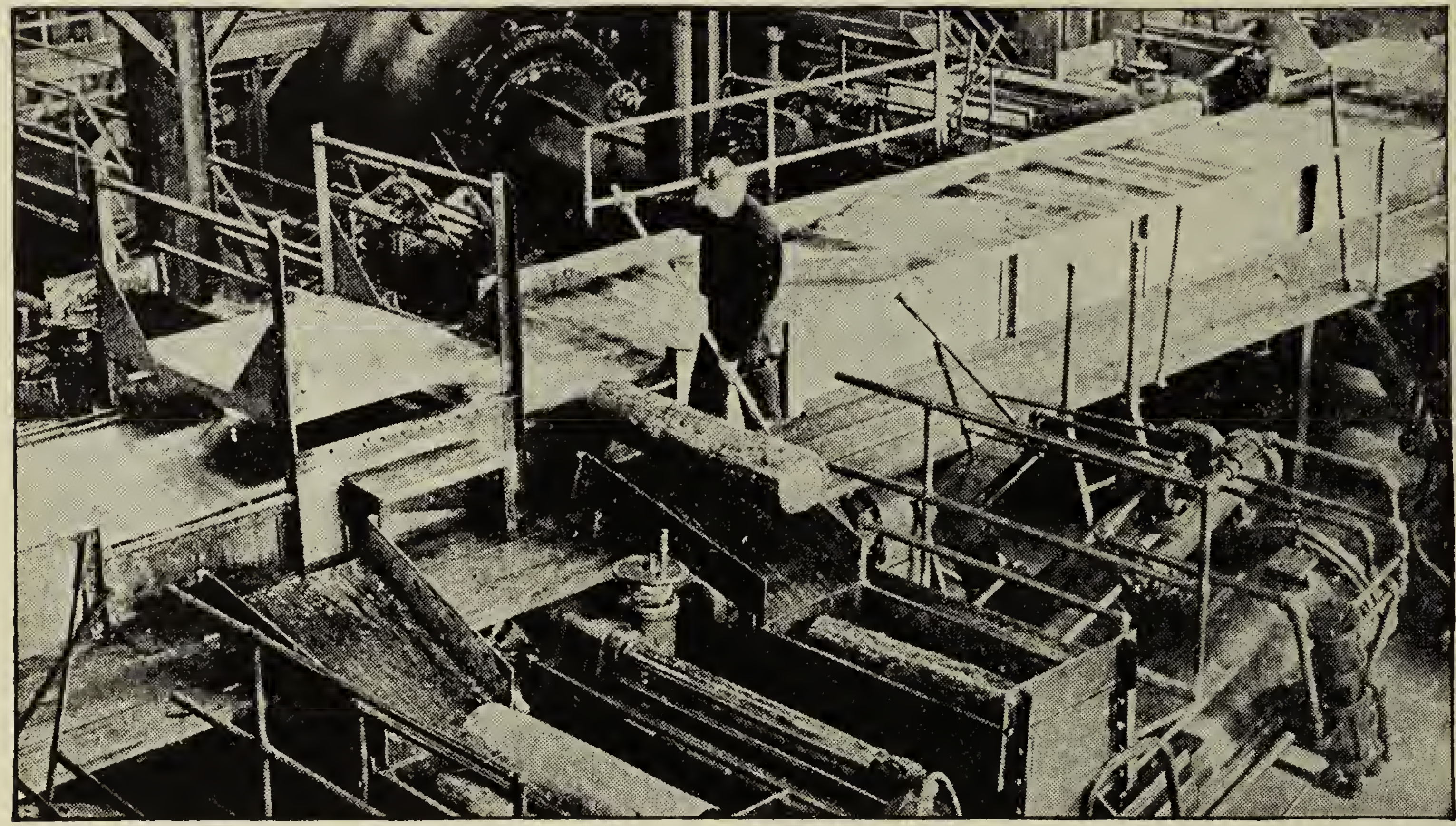
Pulpwood being sorted after bark has been removed in the large revolving drums

Paper. Two thousand years before Christ the ancient Egyptians had prepared and used a special writing material called papyrus. They made this by taking the stem and pith of an aquatic reed, the papyrus plant, placing the fibers in layers, soaking them in water, and pressing the soft, pulpy product into thin sheets. These sheets were dried in the sun and polished with a piece of ivory or a smooth shell. On the papyrus, literary and religious matter and official records were written. Ancient papyrus rolls 15 inches wide and 100 feet long have been found.

The art of making paper with a smooth surface which could be written on seems to have been discovered by the Chinese centuries ago. Its use by European peoples came much later. It was not until about the thirteenth century, however, that the demand for it became general. The invention of the printing press gradually accelerated its use, and the utilization of paper as a protection for foods and other goods, as well as its use in construction work, swelled the demand rapidly.

Paper (the word *paper* is derived from *papyrus*) is made of a variety of materials. Straw, rags, and wood are used, as well as other cellulose material. There are several different processes by which these natural fibers are made into paper, but we are concerned here only with obtaining a general idea of the steps involved.

Much of the wood used in the manufacture of paper receives no chemical treatment whatever. Logs, mostly of spruce and hemlock, are cleanly stripped



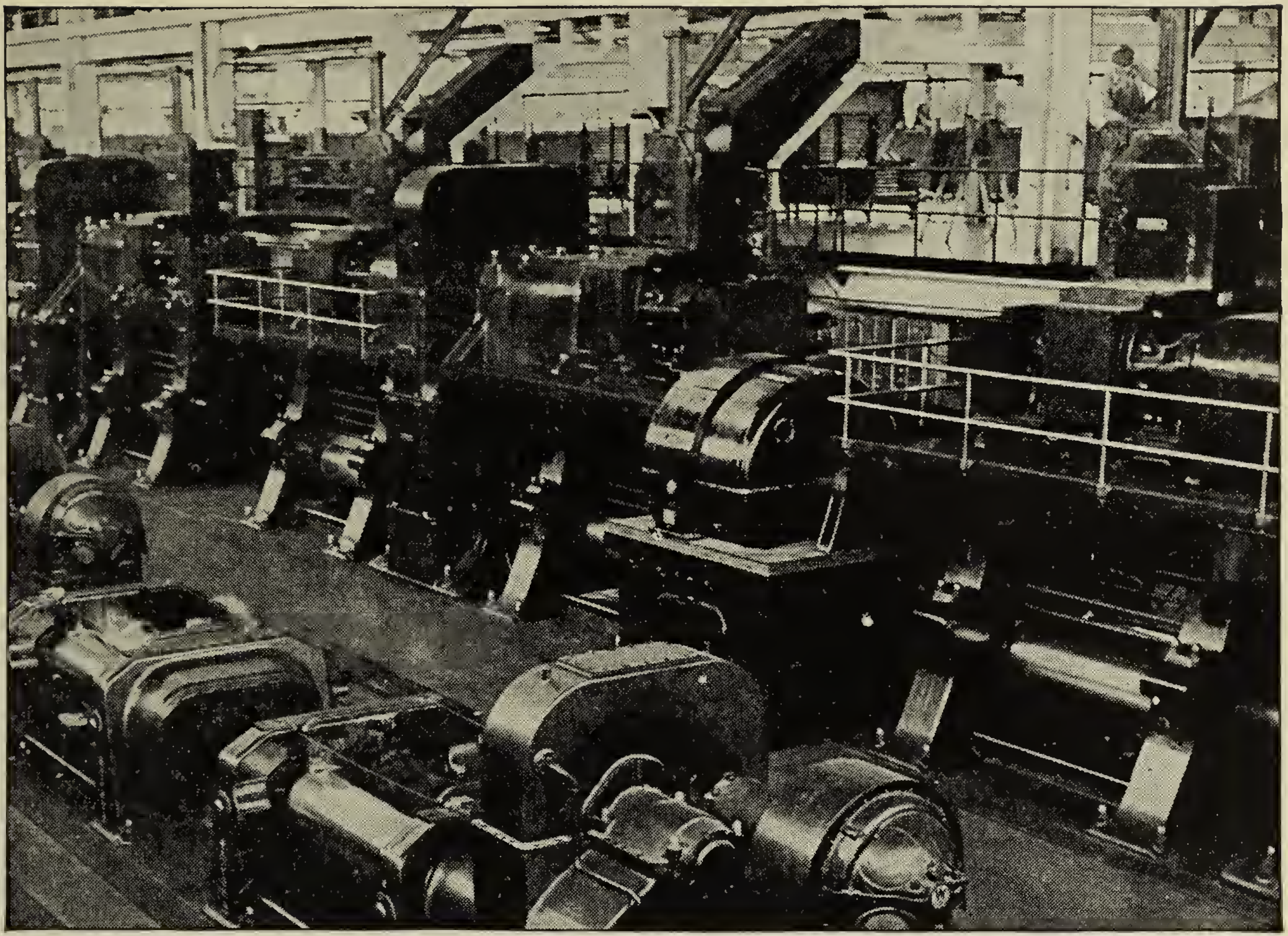
Great Northern Paper Company

Logs being fed into grinder to make pulp, which is chemically treated and made into paper

of their bark, and the wood is then pressed firmly against revolving wood-grinding wheels which are kept wet with water. The woody fibers thus shredded and torn away are separated from the coarser material which may accompany them. This watery pulp is then mixed with other chemically treated wood fibers which act as a binder and is passed directly on to the papermaking machines. These machines press the whole out into thin sheets, which are dried and prepared for use.

Over 500,000 tons of this mechanical wood pulp is produced in the United States each year. Paper made in this way comprises about 80 per cent of that used for ordinary newsprint purposes.

About sixty years ago an American chemist discovered that when shredded wood and chips are treated in a closed vessel with a calcium bisulfite ($Ca(HSO_3)_2$) solution, the noncellulose part of the wood is very largely dissolved out and removed. The residue consists of rather pure fibrous pulp which may be used in papermaking. This process is known as the *sulfite process* of papermaking. The pulp is pressed into sheets by rollers, dried, and prepared for the market. In Canada and the United States alone over 5,000,000 cords of spruce, balsam, and hemlock are converted into wood pulp annually by this process. In addition, before the second World War cut off international trade, large quantities of sulfite wood pulp were imported annually from the Scandinavian countries. Canada, with its magnificent and extensive forests, is a heavy producer of paper pulps of various kinds. In 1939 the



Ford Motor Company

Especially designed mixer to prepare rubber for tires

total output of that country was 2,869,000 tons, of which the United States purchased 2,206,000 tons, or more than 76 per cent of the entire production.

There are other processes by which the softer poplar and similar woods may be made into wood pulp. The resinous pines can also be utilized by yet another process. The final objective, however, is always the same—to get a suitable wood pulp that may be pressed by rollers into sheets which may be dried and finished for the trade.

Rubber. Rubber was formerly obtained exclusively from the latex, or "milk," secured from a number of *wild* tropical trees. More recently it has been found that the milky fluid of many other plants, such as the spurge, guayule, and goldenrod, also yield appreciable quantities of this elastic substance. In recent years domestic plantations of rubber trees have been established in Malaya, the East Indies, Africa, and Brazil to meet the large demand for this product.

Rubber, or caoutchouc, is a complex hydrocarbon of the formula $(C_5H_8)_n$. The latex is obtained from the trees by tapping, and it is coagulated by treatment with acetic acid and subsequent dehydration. Its chief value lies in its imperviousness to water and its high degree of elasticity.

Ford Motor Company

Batch of freshly mixed rubber entering the mill, where it is formed into sheets

In 1839 Charles Goodyear discovered that he could vulcanize rubber by heating it with a small portion of sulfur. When vulcanized, rubber is tougher, stronger, and less sensitive to heat. This discovery greatly extended the purposes for which this material could be employed. As a consequence, its consumption has mounted enormously. It is now used chiefly for rubber tires and tubes, for boots, shoes, and coats, and for belting, garden hose, gloves, rubberized fabrics, and hard-rubber goods of almost all descriptions. Chemical research since 1910 is said to have increased the average mileage of automobile tires from 5000 to 20,000 miles and reduced the cost of a single casing and tube from fifty dollars to fifteen dollars. In the manufacturing processes rubber is blended with many other materials. Some of these are sulfur, carbon black, zinc oxide, and magnesium carbonate. These substances give increased tensile strength and greater wearing qualities to the rubber, although they were originally used as dilutents merely to reduce its cost per pound. The color of the finished product may also be controlled by adding dyes or pigments.

With the world involved in mechanized warfare the demand for rubber has mounted enormously. Moreover, the invasion of the Malay Peninsula and the East Indies by the Japanese forces has prevented the importation of this product by the United Nations. As a result, a great shortage of rubber has occurred. It has been proposed that the United States turn its attention to the utilization of the native guayule plants, which contain considerable rubber. It is estimated that the guayule now growing in the arid Southwestern states would yield one entire year's supply of rubber. Furthermore, it is believed that, as an emergency war measure, this plant could be cultivated advantageously as a source of rubber. In fact, the government is already reported to have begun an experimental venture of 75,000 acres of guayule.

Artificial rubber-like materials have been developed within the past few years. These products are not rubber in the sense that they have the same chemical composition. Neither is there any one of these products that can take the place of true rubber in all its industrial and manufacturing uses. On the other hand, for many special uses rubber-like products have been synthesized which, for particular purposes, may be far superior to rubber itself. One of these is a hydrocarbon derivative called neoprene. This substance is capable of being vulcanized like rubber; and when it is properly combined with other components, materials are produced whose excellence for particular uses far surpasses that of pure rubber itself. For example, rubber is very susceptible to the swelling and deteriorating action of grease and oil. Some of the neoprene derivatives, however, are highly resistant to injury from these agents. Again, it is common experience that exposure to direct sunlight is highly deleterious to natural rubber products. Particularly is this true in the case of such articles as automobile tires and rubber coats. Under such conditions the surface cracks and checks badly. Certain of the rubber-like derivatives, however, are many times more resistant to injury from this source. Other synthetics are as elastic as rubber, if not more so; some offer greater resistance to abrasive forces; some are more chemically resistant; and still others can withstand higher temperatures without undesirable deformations.

Gradually at many points these more desirable synthetic rubber-like compounds are displacing the true latex products. Air and fuel hose, hose for gasoline pumps, transmission belts, conveyer belts, printing-press rollers, covering for electric cables, "rubber" gloves, strip covering for the riveted seams of airplane fuselages, leather cements, fuel-pump diaphragms, shoe soles, waterproofed clothing, and hundreds of molded articles of all kinds are now being made from neoprene.

The crude basic materials from which this synthetic product is made are coal, limestone, and common salt. The chief deterrent to a much wider use is the cost of manufacture. Neoprene is still more expensive than pure rubber.

However, manufacturing costs are constantly being reduced, and new processes are being discovered.

The heavy demand for rubber in war activities has stimulated the use of synthetic rubber to a tremendous degree. Almost all, if not all, the larger rubber companies in the United States have perfected an artificial product which will doubtless largely displace the use of natural rubber as the war progresses. Tentative plans of the United States government call for more than 200,000 tons of synthetic rubber during 1943 and more than twice that much in the year 1944.

Plastics. Other synthetic products which have attracted much attention are *plastics.* The word *plastic* (*resin*) is applied to substances that are amorphous and can be molded into desired shapes. The term is commonly applied to products derived from plants and to a large variety of substances now prepared in the chemical laboratory. Synthetic products are made by first causing the relatively simple molecules to unite, then by appropriate treatment causing these substances to undergo a change in molecular structure so as to form more complex substances.

Most of the plastics are waterproof and can, under proper treatment by temperature and pressure, be molded into different forms. The plastic industry has had a mushroom growth. War demands are expanding it rapidly, and the products are taking the place of many materials, such as wood, metals, and glass.

One of the best-known plastics is *Bakelite.* It is used for handles of cooking utensils, brushes, and umbrellas, for buttons, for telephone receivers, for electric instruments, for parts for automobiles, and many other articles.

Another important plastic is *Lucite.* It is a crystal-clear solid with the optical properties of glass, and can be molded or cut with a saw or knife or tooled in a lathe. A peculiar property of Lucite is that light will traverse a rod of it as within a tube, even though the rod be bent. A number of other plastics are now being produced that are designed for particular uses both in industrial pursuits and in private life.

As an indication of the extent to which artificial products and plastics are entering into modern life the National Geographic Society has recently issued a bulletin in which it states that it would be possible for industrial chemists to clothe the nation now from head to foot with these materials. To make the matter more vivid, they declare that synthetic styles could provide the American girl with a hat of cellophane and a dress, underwear, and gloves of rayon. In addition, she could sport Nylon hose and imitation alligator shoes. Her "jade" bracelet or "ivory" beads would look like the genuine article, while her artificial leather handbag would probably have a plastic frame. Her handkerchief, moreover, could be perfumed with artificial musk, as pleasing to her friends as if extracted from the wild musk ox of the arctic plains.

One of the leading automobile manufacturers, just before the war broke, built an experimental plastic car. It had a rounded nose and a cream-colored body which made it look like the usual steel model. The plastic body, however, consisted of fourteen panels, formed in 1000-ton presses, and attached to a tubular steel frame. By the use of this material the total weight of the car was cut from 3000 to 2000 pounds. Moreover, the panels are reported to have been so strong that they withstood a heavy blow with an ax without appreciable damage. Before the war disrupted the company's plans, the chemist in charge of the experiment had hoped that limited production for the market might be attained by 1943.

Chemical products that owe their existence to the research laboratory are ministering to the needs of modern man in thousands of different ways—for example, as foods, soaps, explosives, drugs, anesthetics, resins, and plastics. We are probably only in the swaddling-clothes stage of the plastic industry. The examples given above amply illustrate the large place which chemistry and its products have come to occupy in modern civilization.

Questions for Study

1. How does the chemist make it possible to develop artificial nitrogen fertilizers?

2. In the refining of sugar from beet juice the sirup is strained through ground limestone to remove the organic impurities. What principle is involved in this purifying process?

3. What are some of the properties of different kinds of glass that fit them for different purposes?

4. What are some of the parts of the modern automobile that are electroplated and for what purposes is this done?

5. Why are metallic alloys being introduced so rapidly into modern manufacturing processes?

6. How do chemical changes enter into the processes employed in refining metallic ores?

7. A bulletin issued by a large industrial company stated that "steel is more important than gold, silver, copper, tin, and lead combined." Do you agree with that statement, and if so, why?

8. A stove or furnace is often made of cast iron, whereas the axle of an automobile is made of fine steel. What is the chief difference between these two forms of iron, and why is each used for the purpose mentioned?

9. Why are many of the modern synthetic dyes preferable to the older, much-prized animal and plant dyes?

10. How has the dye industry contributed to the development of man's aesthetic sense?

11. What in your judgment are some of the chemical products that have influenced modern life most?

12. Why are the silk merchants solicitous regarding the future of the American market for their product?

13. How has the paper industry contributed to the intellectual and cultural life of our nation?

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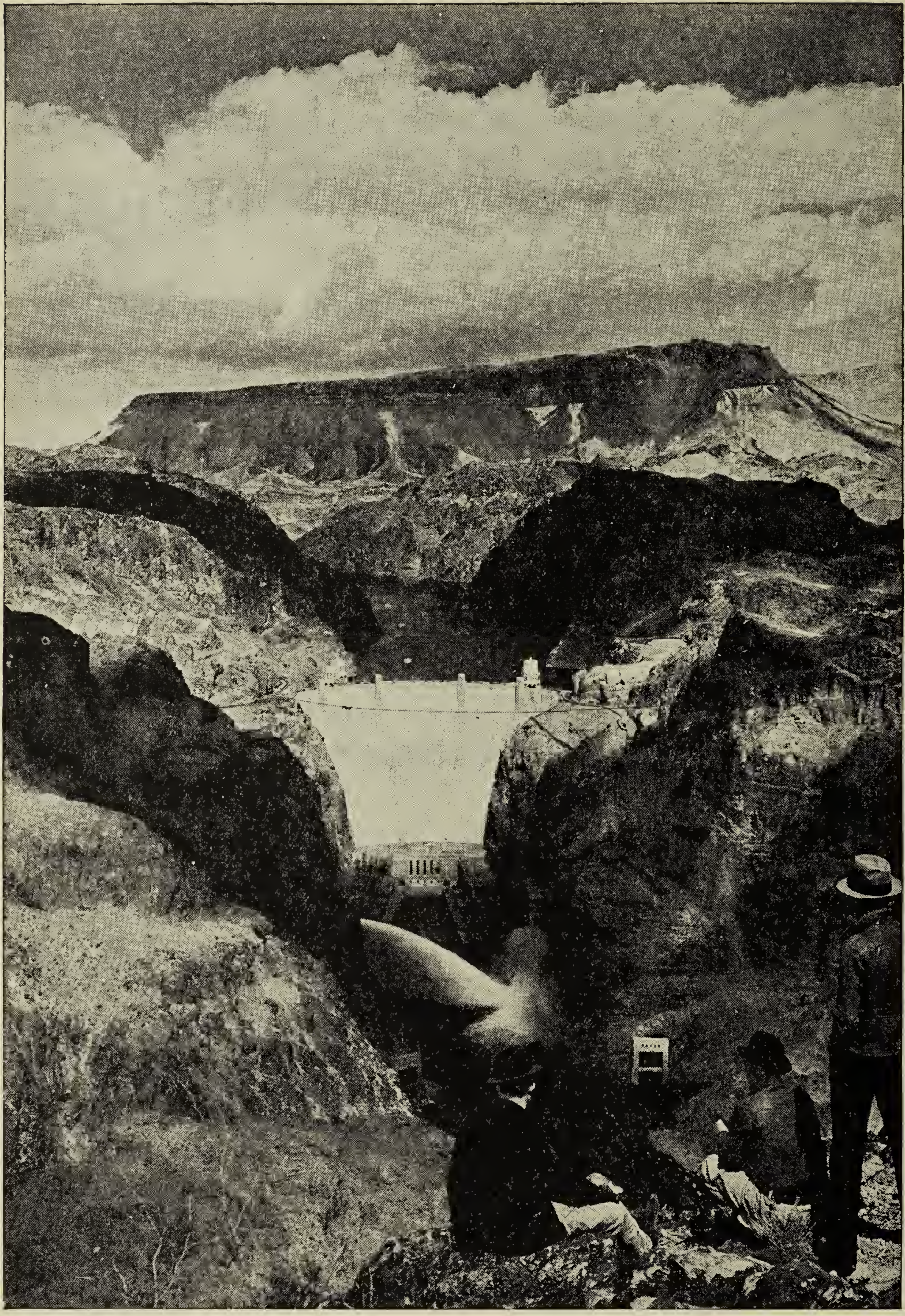
UNIT FOUR

Energy in Many Forms Is Used by Man to Advance Civilization

The original source of the earth's energy is the sun. Like an overgenerous parent the sun sends us two hundred thousand times as much power as we at present are able to use.

Energy appears in many forms; and perhaps, aside from its ability to accomplish tasks, its most striking characteristic is the ease with which it may be changed from one form to another. Largely because of this invaluable quality energy has entered more and more into human experience. It has lifted many of the heavy burdens of toil from men's backs. It is now estimated that, on an average, each dweller in the United States has at his disposal energy equivalent to that produced by one hundred sweaty slaves for the renowned Rameses of Egypt. Energy has increased the tempo of business and social life commensurately. Today one may speak from one continent to another in a fraction of a second, and a bomber plane has been ferried across the Atlantic in four hundred minutes.

Perhaps the most remarkable aspect of modern times is the degree to which man has been able to apply the energy of captured sunlight to make life easy, animated, and interesting.



United States Bureau of Reclamation

Boulder Dam

The power plants are at the bottom of the gorge

CHAPTER SEVENTEEN

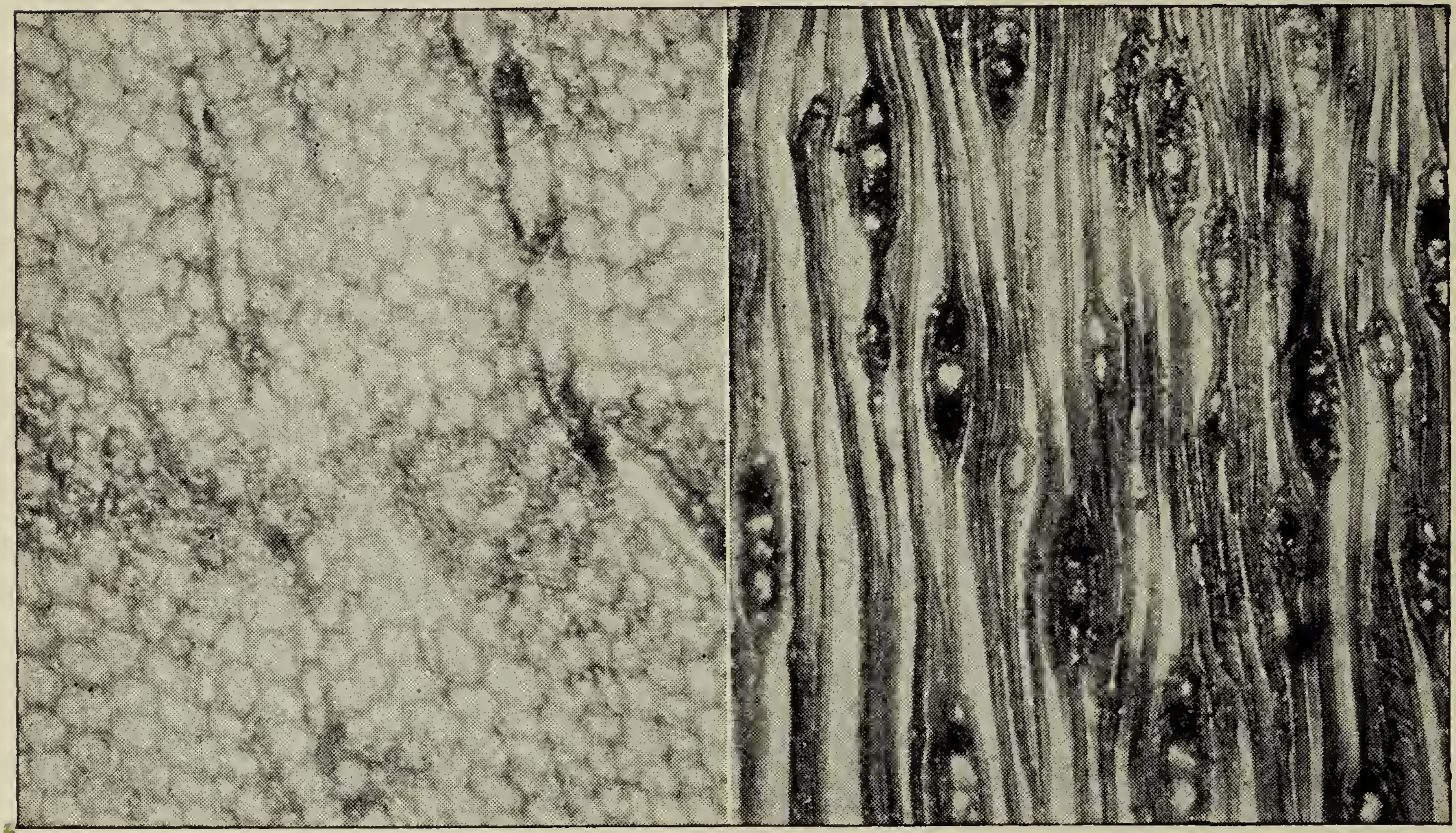
The Earth Is Flooded with Energy, of Which Heat Is a Form Indispensable to Man

The Sun Is the Original Source of Practically All Energy. The world is a place of bustling activity. Animal life is ever on the move, and man-made machines cover the earth and dot the sky. A casual observer from some other planet would think, from what he observed, that energy in a form capable of doing work must be an innate characteristic of the universe and that the supply is unlimited. Physicists, however, tell us otherwise. They state that energy has definite points of origin and that for the earth practically the whole supply comes from the sun. Even the original store locked up in the chemical compounds of the earth came from the sun, too, if one accepts modern theories as to planetary origin.

Although we on the earth receive only one two-billionth of the sun's radiant energy, yet, to quote one writer, "The sun is the greatest utility company by which mankind is benefited." Every square yard of the earth's surface directly exposed to the sun receives, on an average, light equal to $1\frac{1}{2}$ horsepower of energy. If we had to pay for this light at the rate of two cents a kilowatt-hour,—a low rate for electrical energy,—the earth's bill for a single day would be about thirty trillion dollars. To make the picture more vivid, let us limit the area under consideration to Greater New York City. It has been estimated that for this restricted area alone the cost of sunshine, if transformed into electric power, would amount to about one hundred million dollars a day.

Direct solar radiation is of inestimable value as an agent to warm the earth and make it a habitable place, but as a source of industrial power we have found it to be almost negligible. Another agent must intervene to fix this enormous flood of solar energy in forms which in industrial quantities are available to man. Chief of these agents is the green plant.

The minute chloroplasts, or sugar-making organs, within the green cells of plants, in some way not completely understood, have the ability to arrest the light rays and to use the derived energy to make simple sugars and their derivatives, such as starch and cellulose. From these carbohydrates as a base other energy-producing foods, such as fats and proteins, also are believed to be built by the plant. Some of this stored energy is used directly by man



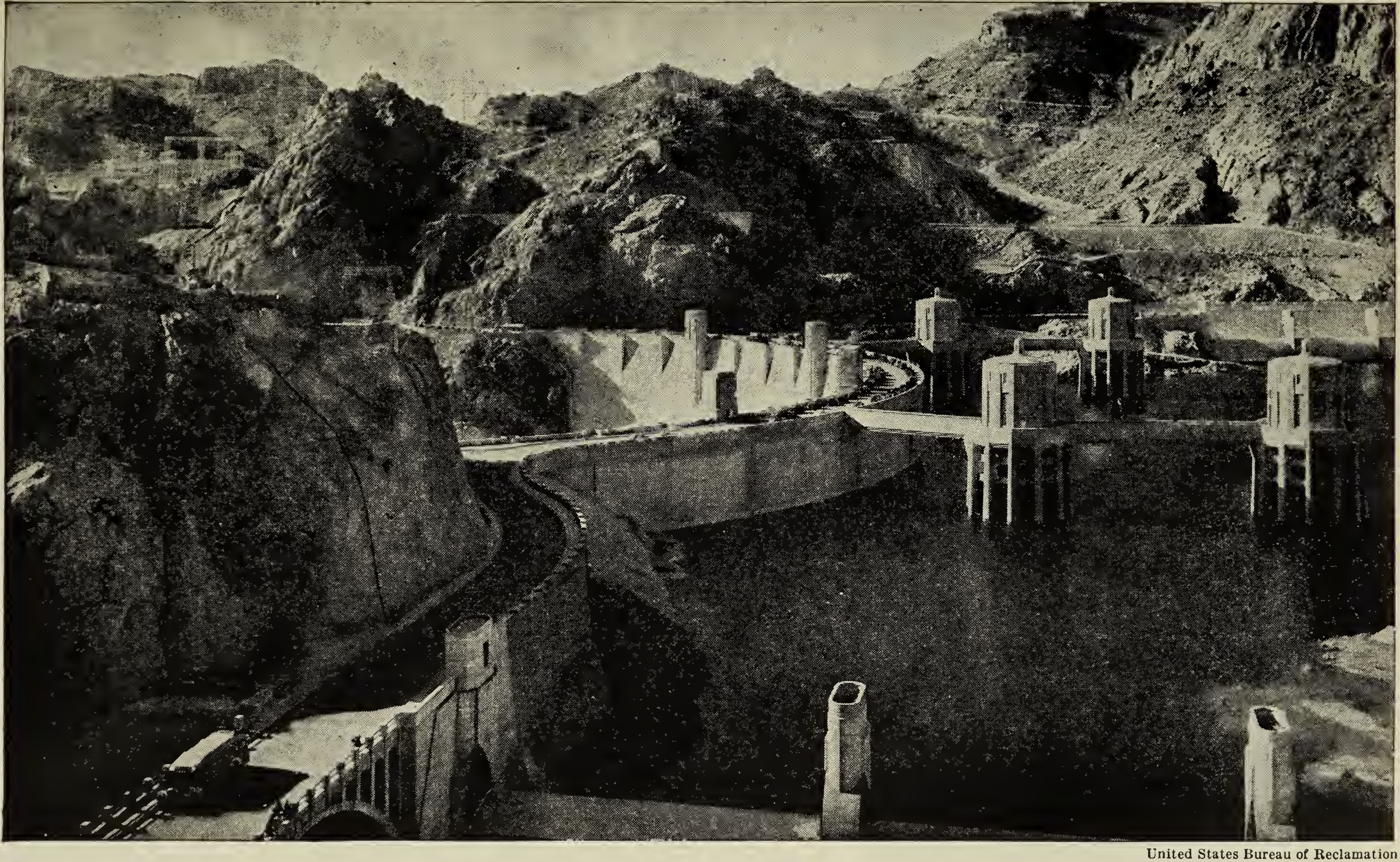
Lignite

A, a thin cross section of lignite showing the structure of the plant tissues of which it is formed; *B*, longitudinal section of the same coal

and other animals in the form of food and fuel, but most of it reaches man in another manner.

In prehistoric times, geologists tell us, the atmosphere was warmer and much more heavily laden with carbon dioxide than it is today. Consequently plant life was much more luxuriant than it is at present. Great amounts of plant matter in the form of tree trunks, stems, leaves, roots, cones, spores, and seeds, which accumulated in swamp regions, were covered in time by soil deposits washed down from higher land elevations. Under these conditions, because of chemical change in the buried plant tissues during a long period of time, great deposits of coal were formed. Petroleum and natural gas are believed to have been derived from plant and animal remains in a similar manner. By means of furnaces and generators this fuel can be transformed into heat, light, and power.

Scientists are now evolving a method by which the energy stored in plant products may be used more directly. Anhydrous alcohol, which may be made from corn, is mixed with gasoline to form a motor fuel. Other farm products, such as low-grade oats, barley, wheat, sorghum, and potatoes, may also be utilized for this purpose. This mixture of alcohol and gasoline can be profitably sold for about twenty-five cents a gallon. If it should prove that industrial fuels can be economically produced in this manner, on a large



United States Bureau of Reclamation

Boulder Dam

The impounded water above the dam

A cut through huge snowdrifts in the Rocky Mountains

scale, the agelong processes of geological change involved in the formation of coal and petroleum may be largely circumvented in the future.

The tremendous flow of energy from the sun is passed on to man by yet another avenue. The average rainfall over the whole earth is about thirty-two inches a year. If this amount fell at one time, it would flood the entire earth to a depth of almost three feet. All this water must first evaporate from the earth's surface under the influence of the sun's rays and be lifted to a cloud height of about 4000 feet. Much of it is condensed and falls as snow. Under the influence of the sun's rays snow and ice gradually melt, and the water derived both from this source and from rain begins to flow down the mountainsides to the sea again. As it goes, it is utilized in hydroelectric plants to generate electric power, which flows out in a colossal tide of energy to do work.

Will Man Ever Be Able to Utilize Subatomic Energy? In previous chapters it has been made clear that atoms possess enormous internal energy. When the nuclei explode spontaneously, they hurl out heavy alpha and lighter beta particles with great force. Often, in addition, hard, penetrating rays of great energy are emitted. Consequently, if the billions of minute packets of atomic energy appearing in even a drop of water could all be liberated and made to flow in a controlled and steady stream of power, the effect would be astounding.

The first experimental success in this direction has been reported. Ordinary uranium has an atomic weight of 238; but an isotope of this element whose atom weighs 235 has been discovered and isolated in microscopic amounts. When this new form of uranium is bombarded with neutrons, the atom is split apart to form two lighter elements, and the change is accompanied by the release of relatively tremendous quantities of energy. This splitting of the uranium atom is computed to release 175,000,000 electron volts. In comparison, when a hydrogen and an oxygen molecule unite,—"perhaps the most terrific explosion of all chemistry,"—but two or three electron volts are produced; and when the notorious TNT detonates, not even that much energy is released. The energy released from uranium appears in the form of heat, and, if enough of it were available, it could be used to run factories, drive steamships, or pull railroad trains.

The possibility of making this change produce a continuous stream of effective energy depends, however, not only on an adequate supply of this particular isotope of uranium but also upon what is known by chemists as a chain reaction, which cannot yet be artificially produced.

Coal as a source of commercial power is not likely soon to be displaced by uranium. In the first place, only a very little of this particular isotope has been separated. Moreover, an increase in consumption, were it possible to use it as a source of commercial power, would probably boost the price far above the limit of practicability. In the second place, the indispensable chain reaction would have to be worked out and brought under reasonable control. So for the present at least the hope of deriving power from this source in commercial amounts is a very faint one.

Another theoretical method of extracting energy from the atom is that of annihilation. Einstein has shown that theoretically the entire mass of the atom may be converted into energy. The equation indicating the results of such a transformation is as follows:

$$\text{Energy} = \text{mass} \times \text{velocity of light}^2$$

Energy here is expressed in ergs[1] and the velocity of light in centimeters per second. If we take a mass of 1 gram and substitute the numerical value for the velocity of light squared, the equation becomes

$$\text{Energy of 1 gram} = 898{,}740{,}411{,}000{,}000{,}000{,}000 \text{ ergs}$$

To make the result more vivid, let us assume that a kernel of corn weighs 1 gram and that the average weight of the 130,000,000 people in the United

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[1] The erg is the amount of work done by 1 dyne acting through a distance of 1 centimeter; and a dyne is that force which, acting on a 1-gram mass for a second, will increase its velocity 1 centimeter per second.

States is 150 pounds. Then, if a kernel of corn could be converted into energy according to this equation, there would result just about enough energy to lift the entire population of the United States two thirds of a mile. To obtain an equivalent amount of energy from coal, under present conditions of combustion, almost 3000 tons would have to be burned.

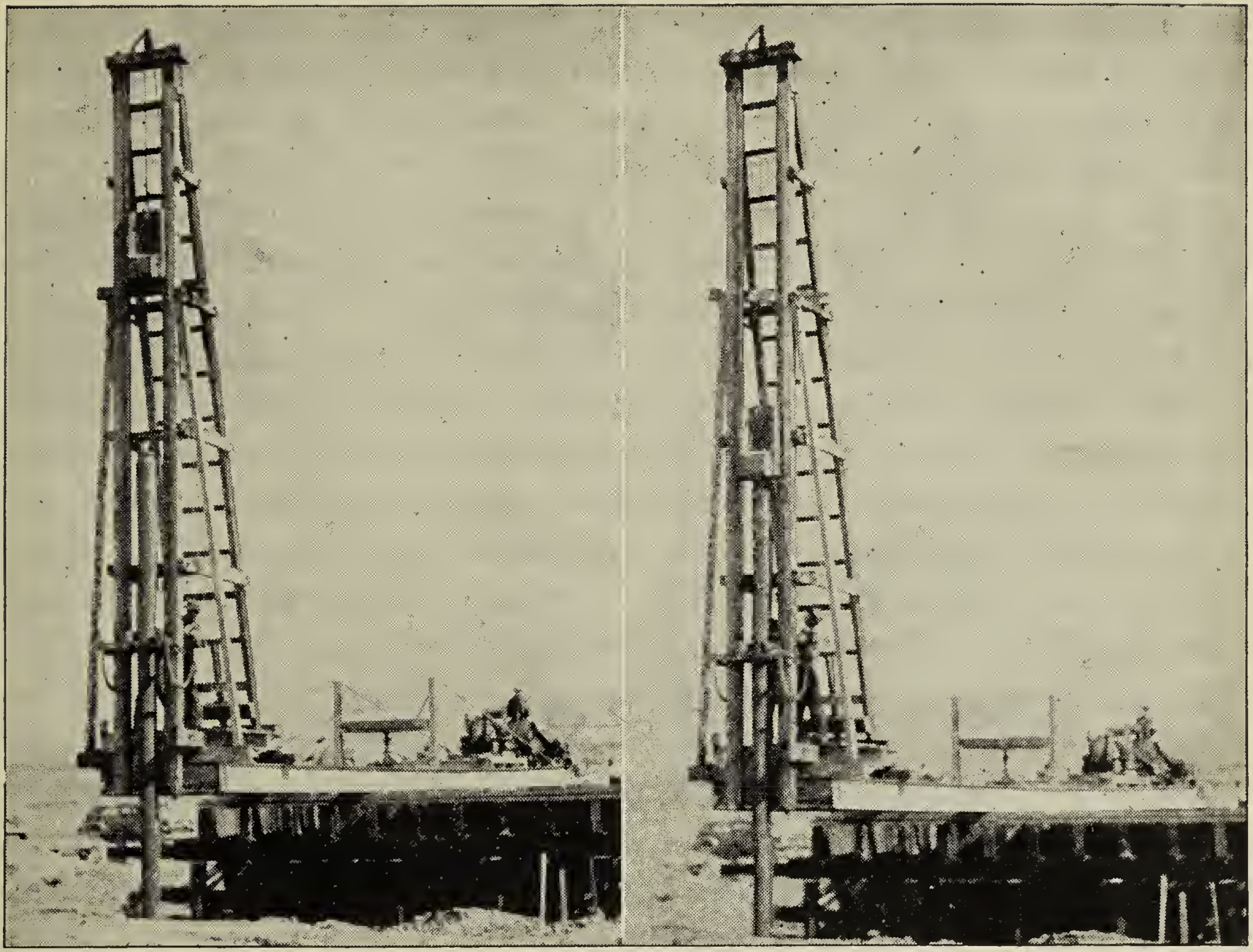
On this same basis we are told that the energy in a breath of air would operate a large airplane continuously for a year, and that the pasteboard in a small railroad ticket would run a heavy passenger train several times around the globe.

Whether man will ever discover how to tap this fabulous store of subatomic energy economically is a question. If he did, power would probably be as cheap as the dirt under his feet, and all other sources of energy, such as coal, petroleum, and water power, would become obsolete. There is no indication of this revolutionary advance at present.

From the sun, then, comes the world's supply of energy. Although terrestrial energy has but one origin, it is not confined, as the reader well knows, to one form of expression. On the contrary, it appears in two different states and in several different forms. It may be changed readily from one to the other.

There Are Two States of Energy. For practical purposes we may say that there are two states of energy: potential and kinetic. Each kind is capable of being transformed into the other. For instance, when large postlike pilings are driven down into the beds of streams to support bridges and roadways, a driving machine called a pile-driver is employed. Its essential part is a large hammer weighing half a ton or more. This is raised by pulleys to the top of a suitable tower, where it is mechanically released and descends as a falling body to strike the piling squarely on the top and drive it down into the bed of the stream.

The big hammer of a pile-driver furnishes a good example of how the two forms of energy differ and how they may be changed from one to the other. The instant the hammer reaches the top of the tower, and just before the "dog" that releases it is sprung, it possesses tremendous energy. It has this energy by virtue of the work done upon it while it was being elevated to its position at the top of the tower. If the decomposing influences of time are disregarded, the hammer could remain at that point for a hundred years and still retain the same amount of energy. This type of energy is energy of position, and is called *potential* energy. The minute the hammer is released, however, it begins to descend and to take on *kinetic* energy, or energy of motion. At the same time its velocity increases, and its kinetic energy thereby



A B

Pile-driver in action

A, showing the 2000-pound weight at the top of its stroke; *B*, the weight strikes the heavy pile, which is being driven into the ground

is augmented; its elevation is lowered, and its potential energy in turn is diminished. This transfer of one kind of energy into the other continues until the instant when the hammer just reaches the top of the piling. Now it has lost all its potential energy and, if friction is disregarded, has gained an exactly equal amount of kinetic energy which can be used on the top of the piling to do work and drive it into the earth. This example illustrates the intimate and interchangeable relation of these two states of energy.

Of the two forms, potential energy is the silent, unostentatious one, whereas kinetic energy is the active, conspicuous one. Potential energy may be energy of position, as when rocks are lifted high in the air by geological forces or when particles of water vapor are released by the sun and carried skyward; it may be chemical energy stored millenniums ago in coal and oil by the action of plants; or it may be electrical, as when a charge gathers on a cloud just before the lightning crashes. Any motion initiated by potential energy immediately manifests itself as some form of kinetic energy.

Heat Is a Most Important Form of Energy. Heat is one of the most common and necessary forms of energy; yet man at first seems to have given little thought to its nature. Fire was much more challenging to him, which, although it emits heat, is an entirely different thing.

Then during the seventeenth century came Boyle and Newton. They regarded matter as being composed of infinitesimally minute particles and thought that heat in some way caused these particles to vibrate. In the eighteenth century men came to look upon heat as an imponderable fluid that was able to force its way in between the tiny particles of the densest body. For this substance Lavoisier, in 1789, coined the term *caloric*, which, had the fluid really existed, would have been a most appropriate name. It is from this fantastic conception that we have derived the term *calorie*, which we apply to our unit of heat today. "Caloric" was regarded as composed of extremely refined and tenuous corpuscles which were very elastic and mutually repellent but which were readily attracted by other forms of matter. It was too intangible to be weighed and too elusive for man to capture and examine. This imponderable "caloric" continued to enjoy a prominent reputation throughout the greater part of the eighteenth century. The brilliant Lavoisier even went so far as to include it in his *Elements of Chemistry* as a chemical element along with copper, iron, oxygen, sulfur, and others.

Joseph Black Discovers Latent Heat. One of the most fruitful workers in the field of heat was Joseph Black, the son of a Scotch wine merchant. Born in 1728, Black enjoyed the advantages of a university education and later became a professor of chemistry and medicine at the University of Edinburgh. He observed that when ice is placed in a pitcher of water, the temperature of the water falls to approximately the freezing point and that this temperature is held by both the original water and the water formed by the melting ice until the latter has all liquefied. Even if heat be applied, the melting of the ice is hastened, but the temperature of the water remains the same. Now ice makes things cold as it melts; then it must absorb "caloric" from them, reasoned Black. We now know that when a pound of ice at 0° C is placed in a pound of water at a temperature of 80° C, the whole becomes liquid at 0° C. In other words, it takes all the heat in a pound of water at the given temperature to loosen the crystallizing force among the molecules in an equal weight of ice and permit them to become a liquid. Expressed in more modern terms, we say that it takes eighty calories of heat to fuse, or melt, one gram of ice. It is precisely for this reason that ice can be used as a refrigerant.

Apparently many people do not know that ice is used as a refrigerant because it absorbs heat in melting. They think that "cold" is something which the ice gives off to surrounding bodies rather than that the temperature of these bodies is lowered because the melting ice absorbs heat from them. Formerly it was often the practice among many people, in order to conserve ice, to wrap it with paper before placing it in the refrigerator. Is it any wonder that these same people in very warm weather experienced difficulty in keeping the family supply of milk from souring?

Now because all this heat in the water apparently disappeared, bringing the whole to the temperature of the ice to start with, Black said that it had become concealed. So, digging about in his vocabulary for an appropriate word to apply to this heat that had become insensible, he struck upon the word *latent*, which comes from the Latin *latere*, meaning "to hide." So this is how it came about that all the heat rendered insensible when iron, ice, snow, lead, and other solids are melted is called latent heat. The rapid transfer of sensible heat into latent heat is well illustrated on a sunny spring day following a soft, heavy snow the night before. Although the sun shines with full intensity and there is every apparent reason to expect the atmosphere to warm up rapidly, it does not. The day remains chilly. The explanation is readily found in the great quantities of heat taken up and rendered latent by the melting snow.

Whether Black suspected the converse of his discovery or not, we do not know. But in the light of modern knowledge it is perfectly evident that all the heat which is rendered insensible when solids, such as ice, melt is not destroyed. One cannot annihilate energy in that way. On the contrary, if this heat is used up to do the work of changing the solid molecules into the liquid form, it must be liberated again whenever water freezes or molten metals pass back into the solid state. This is precisely what we find, and this insensible energy is released in the form of sensible heat whenever liquids solidify. This transformation of latent heat into sensible heat is often employed in a utilitarian way. In cold weather, when the temperature of vegetable cellars is in danger of dropping just far enough below the freezing point to freeze the vegetables, tubs or barrels of water are often placed in them. The large amount of heat liberated by the water as it cools, and especially that which is generated as it tends to freeze, is sufficient to prevent serious loss from frost. It seems strange to think of freezing water as acting in the capacity of a heater, but that is what happens in this case.

Latent Heat of Vaporization. Black is known to have discovered the even greater concealment of heat in the process of evaporation. For instance, when a kettle of pure water is placed over a lighted gas burner, its temperature begins to rise and continues to do so until the boiling point is reached. But when the water reaches the boiling point, its temperature does not mount higher, although a vigorous flame may be kept burning. True, the water becomes agitated and bubbles violently; but the temperature, if the kettle is at sea level, stays at the 100° C mark. Where does all the extra heat go? Black again reasoned that the "caloric" was hidden, just as in the case of the melting ice. In this instance, however, the energy was used to break down completely the cohesive force in the liquid and liberate the molecules in the form of vapor. This heat came to be known as the *latent heat of vaporization.* The amount of heat so concealed is very much greater per unit of water than when ice is melted. When water is transformed into the gaseous state, it takes about 536 calories of heat per gram, or over five times as much as is required to effect the solid-to-liquid change. This is another reason why melting snow on a bright, sunny day in late spring keeps the air cool, if, indeed, not chilly. It takes 80 calories of heat to melt each gram of snow at 0° C, and then, for whatever fractional part of it evaporates, it requires a corresponding part of 536 calories in addition. Since both the heat of fusion and the heat of vaporization are rendered insensible, it can easily be seen why such days are likely to be uncomfortably cool, even though the bright sun would indicate a very different condition.

One of the most interesting and marvelous adaptations in all nature is the way the temperature of the animal body is controlled through the principle of the latent heat of vaporization. The temperature of all warm-blooded animals is rather closely adjusted and cannot shift up or down very far without great discomfort and serious consequences. For instance, man's body temperature is normally 98.6° F, and a rise of three or four degrees results in a high fever, and one of seven or eight degrees is usually fatal. So in hot weather, particularly if the individual is exerting himself, the heat generated in the body must be disposed of in such a way as to hold the temperature down. Nature has met the difficulty efficiently by introducing the physiological function of sweating, which depends on the principle of latent heat for its effectiveness. As we shall see later, not only is a great deal of heat required to raise the temperature of water after it is drunk, but proportionally much more heat is required to evaporate the water after it is poured out on the surface of the body as perspiration.

This type of heat adjustment holds true for all warm-blooded animals well supplied with sudoriferous glands. In the case of animals with very few sweat glands, if any, such as the dog, the body temperature is held down by a rapid evaporation of water from its mouth and tongue. Much evaporation also takes place from the surface of the lungs, owing to the extremely rapid panting of the animal, although perhaps the chief cooling advantage here is the forced ventilation resulting from the quickened exchange of pulmonary air.

It is evident, if such a prodigious quantity of heat is rendered insensible every time a gram of water evaporates, that the same energy must be liberated again in the form of sensible heat whenever the vapor condenses into a liquid. This principle of latent heat is of utmost importance in steam and vapor heating plants. It is the latent heat of vaporization, also, that enables travelers crossing the desert to keep their drinking-water cool when carried in canvas water bags. Moreover, it is for this reason that a feverish patient who has an alcohol rub feels cooled and refreshed or that a bather coming out of the water into the air, even in the heat of midsummer, experiences a chilly sensation.

Specific Heat. Joseph Black also recognized another very important principle connected with heat, which we have come to recognize as *specific heat*—namely, that equal weights of different substances require widely different amounts of heat to raise them through one degree of temperature. Suppose that one should take 1000 grams of pure water and pour into it a steady stream of heat from a Bunsen burner. The temperature of the water would rise, but the rise would be very gradual. If at the same time an equal stream of heat could be poured into 1000 grams of iron and all of it be retained, its temperature would mount much more rapidly than that of the water. The difference in the response of these substances to heat, then, must be innate; the water must have a greater heat-absorbing capacity than the iron. This is precisely what Black found out. For instance, if we should take one gram of water, at 15° C we should find that it would take exactly one calorie of heat to raise it 1° C. But if we applied a calorie of heat to a gram of iron, the results would be entirely different, for instead of rising one degree the temperature of the iron would rise almost ten degrees. In other words, it takes about ten times as much heat to produce the same temperature effect in water as in iron. Different elements vary widely in this respect. The ability of equal weights of substances, then, to absorb different amounts of heat to produce the same temperature effect is called their *heat capacity.*

Among liquids, water has an extremely high heat capacity, in truth one of the highest of any common substance known, either liquid or solid. Perhaps for this reason largely, water has been adopted as the yardstick to measure the heat capacity of other bodies, and the result of the comparison is called the specific heat of a substance. It is expressed as a decimal fraction. For example, the specific heat of water is arbitrarily taken as unity. But since it takes but about one-tenth as much heat to produce the same temperature effect in iron, physicists say that the specific heat of iron, then, is, roughly speaking, 0.10. Below are the specific heats of a few common elements and the number of grams of each that could be raised 1° C by applying the same amount of heat as that required to raise one gram of water 1° C.

Element	Specific Heat	Number of Grams That Could Be Raised 1° C in Temperature as Compared with 1 Gram of Water
Water	1.0	1.0
Sodium	0.2934	3.4
Carbon	0.238	4.2
Aluminum	0.2022	4.9
Nickel	0.10842	9.2
Mercury	0.0319	31.4
Lead	0.0315	31.7
Gold	0.03035	32.9

The very high specific heat of water is of great importance with reference to climate; for it is evident that if it takes a great deal of heat to warm water, the same water will give off correspondingly large quantities of heat when cooled. For instance, the continents of the Southern Hemisphere, where the proportion of water is much greater, have a decidedly more equable climate than those of the Northern Hemisphere, where the water area is much smaller. In the summertime in the Southern Hemisphere the extensive oceans absorb almost unbelievable quantities of the sun's heat, though the temperature of the water is not raised more than 4° or 5° C. This exerts a cooling effect on the land. Then, in the wintertime, this heat is slowly radiated and tends to keep the land areas much warmer than they would otherwise be.

It is this high heat capacity of water, too, that causes the Gulf Stream and the Japan Current to exert such a great modifying influence on the climate of the northwest coast of Europe and of the United States. These ocean currents are some of nature's mammoth hot-water heating systems in which heat picked up in the tropics is conveyed to the coastlands of these countries. Were it not for this property of water, springs that now remain open during the cold winter to slake the thirst of innumerable wild animals would freeze over, and thousands of these creatures would perish. Incidentally, too, it is this same principle that makes hot-water bottles serviceable as prolonged sources of heat.

"Caloric" is discredited. Joseph Black's discoveries in the field of heat carried implications of the greatest scientific and practical import, as we have seen. Nevertheless all through his work he was laboring under the influence of a monumental error—namely, that "caloric" was an imponderable something which could exist separate and distinct from matter, yet which could, in some unexplained way, enter into the most intimate association with matter.

Not only throughout Black's lifetime (he died in 1799) but far into the nineteenth century this error continued to show its hoary head and bid for recognition. This long period of respectability enjoyed by "caloric" shows how slowly our body of scientific knowledge has grown up, and that truth, like the wheat in the parable, is often mixed with the tares of error. It was not until the day of Count Rumford and Sir Humphry Davy that "caloric" was discredited.

Benjamin Thompson, born in a humble New England home, possessed a brilliant mind, and as he grew up was intensely interested in natural phenomena. It is said that at one time he walked eight miles to hear the lectures of Professor John Winthrop on natural philosophy at Harvard. Later he crossed the Atlantic and entered into the service of the Elector of Bavaria and became very active in promoting industrial developments of all kinds. By the Elector he was honored with the title "Count Rumford."

Regardless of where Count Rumford went, he was always interested in scientific matters and was ever a keen observer. One day while boring the barrels of cannon at Munich he was surprised by the amount of heat generated by the drill. Where does this heat come from and what is its nature were the questions now uppermost in his reflective mind. He arranged a vessel around the cannon barrel that was being bored, filled it with 18¾ pounds of water, and, by using a blunt steel borer to increase the friction, was able to heat the water to 142° F within an hour and a half. At the end of two and a half hours it "actually boiled," reported Rumford. His experiment seems to have excited great popular interest too, for he tells us:

> It is difficult to describe the surprise and astonishment expressed in the countenances of the bystanders, on seeing so large a quantity of cold water heated, and actually made to boil without any fire—yet I acknowledge fairly that it afforded me a degree of childish pleasure, which, were I ambitious of the reputation of a *grave philosopher*, I ought most certainly rather to hide than to discover.[1]

He continues to tell us that the source of heat appeared to be inexhaustible, from which he inferred that heat is not a form of matter at all. He argued that it seemed unnecessary to add that anything which a heat-insulated body can continue to furnish *without limitation* "cannot possibly be a material substance." As a result of his careful, if somewhat spectacular, experiments he came to blows at once with the old "caloric" idea and decided that it was impossible to reach any conclusion other than that heat instead of being a kind of matter is a form of *motion.* He even went so far as to write a friend in 1804 to this effect: "I am persuaded that I shall live a sufficiently long time to have the satisfaction of seeing 'caloric' interred with phlogiston in the same tomb."[1]

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[1] *The Complete Works of Count Rumford*, Vol. I, p. 487. Published by the American Academy of Arts and Sciences, Boston.

Rumford's revolutionary conclusions were vigorously attacked by the calorists, of course, but Sir Humphry Davy soon came to the rescue. Davy, by means of a clocklike mechanism, rubbed two pieces of ice together and got them to melt without the addition of external heat. When his experiment was criticized on the grounds that the "caloric" had come from the surrounding air, he promptly put the whole apparatus in a glass container, exhausted the air with an air pump, and proceeded to melt the ice in exactly the same way as before. From this he concluded that the corpuscles of bodies are set in vibration by the energy of friction in some way, and that "this vibration is heat." Here we have the clear recognition that heat is a form of *corpuscular or molecular motion.* Although the public was slow to accept this view, every reliable experiment from that day to this has corroborated Davy's conclusion that heat is molecular motion.

All bodies possess some heat. With a very few exceptions, to be noted later, man has always been able, under suitable conditions, to lower the temperature of any object he might choose. This indicates that it possesses heat. If it has heat, then it has molecular motion, for that is what heat is. In this way it may easily be seen how physicists, once they had accepted the molecular-motion theory of heat, were logically and inevitably driven to accept the kinetic theory of matter. Even ice has a great deal of heat energy in it. Rumford estimated that there is enough kinetic molecular energy in a piece of ice the size of a baseball, were it released, to raise a ton weight more than thirty feet vertically.

Even the molecules of man's body are vibrating. Sometimes they vibrate more rapidly than at other times, and we are hot; sometimes more slowly than usual, and we become chilled. Floyd Darrow asks whether we have ever beaten our hands about our shoulders to get them warm. If so, he declares, we were only speeding up the molecules to increase their energy content. The molecules comprising our flesh are always vibrating, but they must go neither too fast nor too slow lest we suffer discomfort. If a bather, during a hot midsummer day, sits too long on a sandy beach, his blood is heated, the sweat pores open, and perspiration begins to flow. The result may be a feeling of extreme discomfort, caused largely by the undue speeding up of the molecules. On the other hand, if a person sits in a cold room, a feeling of equal discomfort is produced. In this case the oscillation of the body particles becomes too slow. To compensate, the peripheral blood vessels contract, forcing the blood deeper within the tissues; the liver pours more sugar into the blood to intensify the body fires; and ultimately the muscles begin to shake in an attempt to heat the body through the work of muscular contraction.

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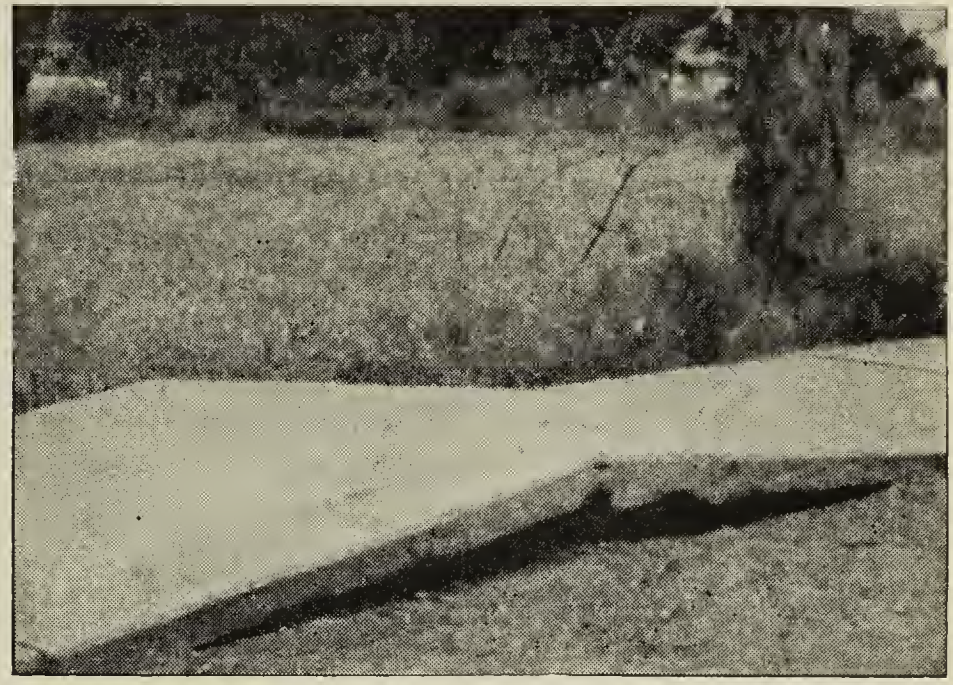
[1] Phlogiston was believed to be an imponderable, invisible substance that passed off from a burning object into the air. Careful students during the first part of the nineteenth century proved that this belief was false.



The buckling of a concrete sidewalk

This buckling was due to expansion caused by the absorbed rays of the summer sun

So the rather narrow limits of temperature which are conducive to life make necessary a proper regulation of the speed of the body particles. If we are too hot, we seek the shade, drink ice water, and fan ourselves to slow down the molecules; if we are too cold, we request the janitor to turn more heat into the apartment to speed up the molecules.

Expansions and Contractions Are Due to Changes in Temperature. We have found that heat is expressed as molecular motion. We can be conscious of it, and, indeed, it can exist in no other form. Because of this fact the addition or subtraction of heat with reference to a body always produces a change in its molecular condition.

Appreciable differences in the length of steel rails are often produced by the day and night temperatures of summertime. One July day a small boy in the middle states was sitting on a railroad bridge across a river, fishing. He was thoroughly startled by the loud, hammer-like reports that came from the rails as midday approached. At first he was completely mystified. Inanimate matter seemed quite alive and to be expressing some kind of agony in sledgehammer "thuds" that shook the whole bridge. A hurried question put to his father, who also was fishing close by, apprised the boy of how substances act when heated. From this explanation the boy easily inferred it to be molecular expansion that was causing the bridge to "pound." During a week of unseasonably cold weather in 1937 it was found that the great San Francisco–

Oakland bridge had shrunk 4 feet, 5 inches in length as the result of the contraction of the metal of which the giant suspending cables are made.

The principle of expansion and contraction is employed in an almost endless variety of ways by man in his everyday affairs. Thermometers used in our homes, offices, and factories, and by the Weather Bureau in particular, all depend on the principle of expansion and contraction for their action. Thermostats and other heat-controlling devices likewise work upon the same principle. In connection with electrically controlled furnaces a fall in temperature within the building to be warmed contracts a specially constructed bimetallic strip, which contraction causes the strip to bend in one direction. As it bends, it makes a contact which closes an electric circuit designed to open the furnace draft. When the temperature is too high, the bimetallic strip by expansion bends in the opposite direction, thereby breaking the first circuit and closing a second one, which operates a device to close the furnace draft. Steel tires, after being slightly shortened, are made tight on wagon wheels by first expanding them with heat to get them on and then letting them set securely about the wooden rim as they cool; tires are shrunk on the big driving wheels of locomotives in the same way; the final spans of big bridges are sometimes packed in ice for several hours to shrink them before they are set into place. In the home the same idea is employed when the screw lids of jars are loosened by dipping them in hot water for a moment; nuts set tightly on bolts and rusted on can often be unscrewed easily after heating them for a short time with a blowtorch. The expansion breaks the corroded joint. Sidewalks and pavements when built must always have expansion joints to prevent them from buckling and cracking during the high temperatures of summer (see figure on page 281).

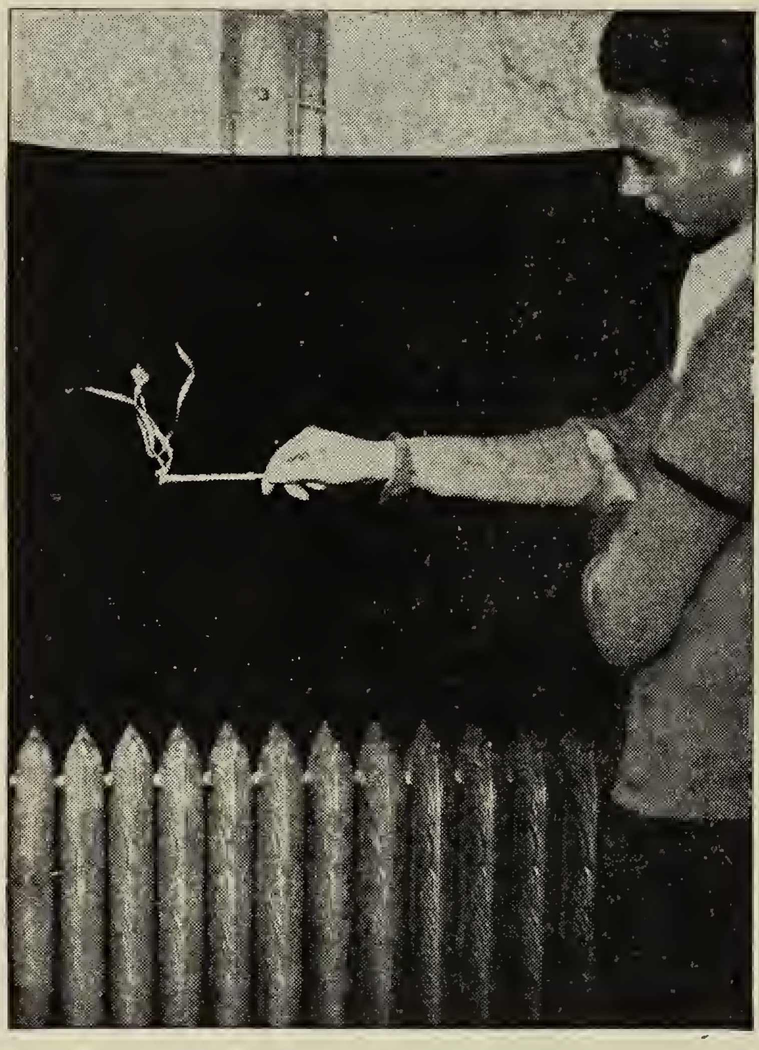
The use of the principle of expansion and contraction is splendidly illustrated in the case of the compensating pendulum. Pendulums, as you know, are employed to regulate the speed of clocks; the longer the pendulum is, the slower the clock runs, and vice versa. The pendulum rod is usually made of metal, and a difficulty is encountered because the rod, owing to contraction and expansion, shortens or lengthens as the temperature varies. This change in length makes the clock run either too fast or too slow. Wood was tried out as a rod; and while it did not respond much to changes in temperature, it did swell or shrink in response to changes in humidity. Finally the difficulty was ingeniously overcome by using an iron rod and setting in the bob a couple of chambers containing mercury. Mercury, when heated, expands more than three times as much as iron. Consequently, as the rod expands, lowering the bob, the mercury at the same time expands upward to raise the center of oscillation. If the rod contracts, raising the bob, then the mercury contracts downward to lower the center of oscillation. In this way the contractions and expansions compensate one another, and the clock runs uniformly. By this method pendulum clocks have been perfected that will not vary in their rate of running more than two hundredths of a second in a month.

Frozen milk

Milk as it freezes in the bottle expands, forcing off the cap ahead of a column of frozen milk

Of all states of matter, gases show the greatest expansion and contraction under the influence of heat. This is to be expected, of course, since the molecules are practically unrestrained by cohesive forces. Charles found, as we have already discovered, that in a gas at 0° C, as heat is withdrawn, thus permitting the molecules to slow down and to come closer together, the volume of the gas is decreased approximately $\frac{1}{273}$ of its zero-degree volume for a fall of 1° C. Then, he reasoned, if one could continue to reduce the temperature, when he reached approximately $-273°$ C all molecular action would stop and the body would be *absolutely cold.* This point Lord Kelvin called absolute zero. It is also evident that if the gas continued to shrink at the original rate, it would cease to have volume too at this point. This would be a strange anomaly, indeed. In reality, however, this could never happen; for the gas would cool to the point where the speed of the molecules would be sufficiently decreased to form either a liquid or a solid long before the absolute-zero point was reached. Then, from that point on, the volume of the substance would cease to shrink at the same rate. Absolute zero has never yet been attained, although it has been closely approximated. Professor W. J. De Haas and his colleagues, working at the University of Leyden, have attained a temperature of $-272.995°$ C.

While we are on the subject of expansion and contraction due to temperature, it will be of interest to note another rather unexpected result. Most liquids, when they solidify through cooling, show a marked shrinkage in volume; a pan of melted paraffin, for example, when it solidifies, almost invariably has a depression in the upper surface; but water behaves in an entirely different manner. As it is cooled from normal temperatures, it contracts as all liquids would normally be expected to do until it reaches 4° C, when it begins to expand. When it changes into ice, there is a marked expansion, which increases its volume almost 10 per cent, thereby causing the ice to be considerably lighter per unit of volume than water. For this reason icebergs float, and shipping is often endangered by them during the early summer in the North Atlantic waters.

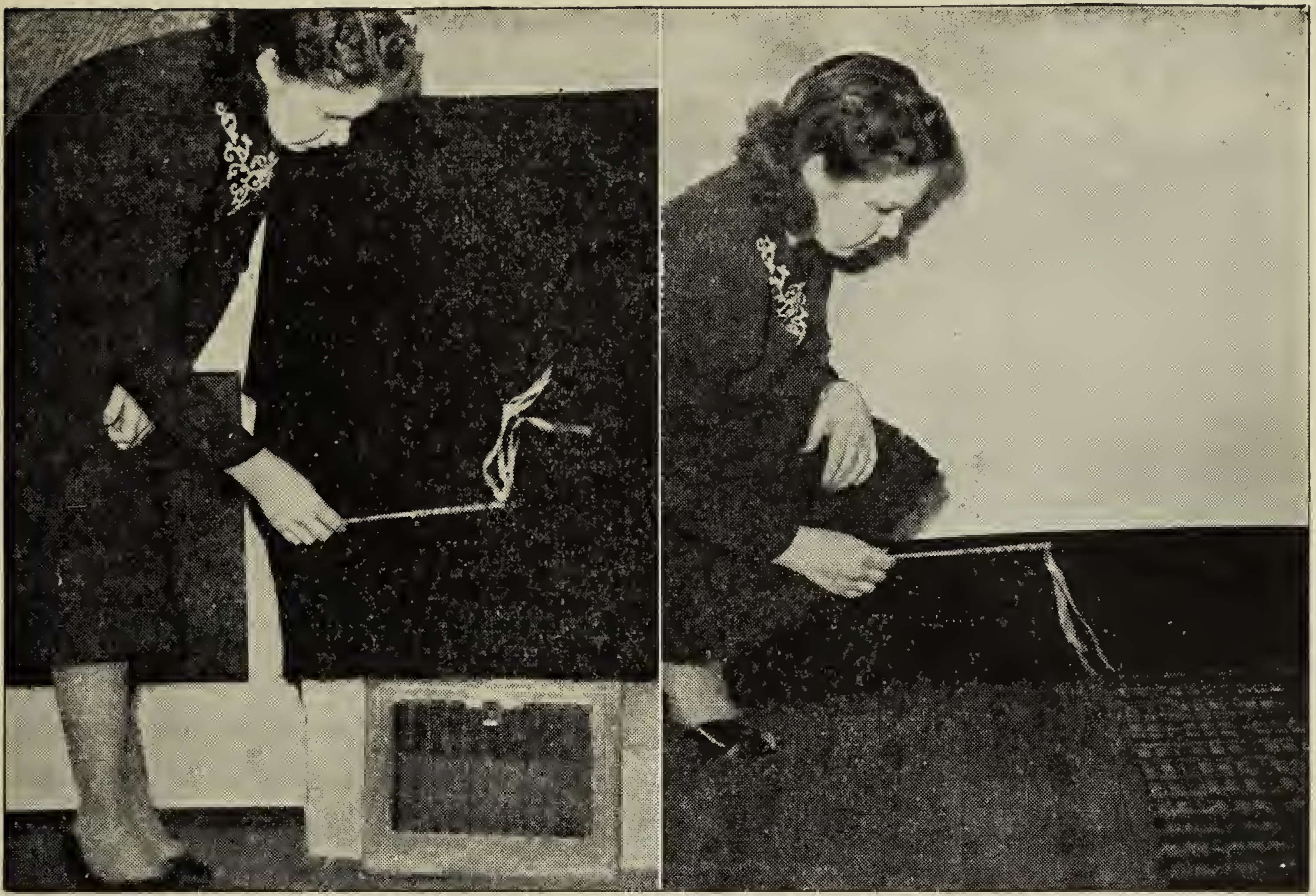


Convection currents in the air over a radiator

This expansion of water as it freezes, however, is of very great importance in nature. When lakes and rivers freeze over, the ice, instead of sinking, remains on top and prevents the heat in the unfrozen water below from escaping into the air. If the ice had a greater density than water, it would sink, and the body of water, freezing from beneath upward, would in very cold weather become a solid mass of ice from bottom to top; and practically all submerged aquatic life would perish. As it is, however, the thicker the ice gets, the better does it insulate the water below; and as a result rivers and lakes seldom freeze over to a depth of more than two or three feet, thus preserving fish and other water life.

There are a few other substances—for example, antimony and bismuth——that expand when passing from the liquid to the solid state. This characteristic of type metal is invaluable. Type metal is an alloy, usually of antimony, lead, and tin. The molten metal expands when it solidifies in the molds, and this causes the letters to be clear, sharp, and well formed.

It now becomes evident that heat is a most indispensable form of energy. Without it life would be unthinkable. The wheels of industry driven by gasoline and steam engines would stop instantly. Water would not evaporate and pass to the mountain heights, there to be condensed into rain again capable of turning water wheels on its subsequent journey back to the plains. All



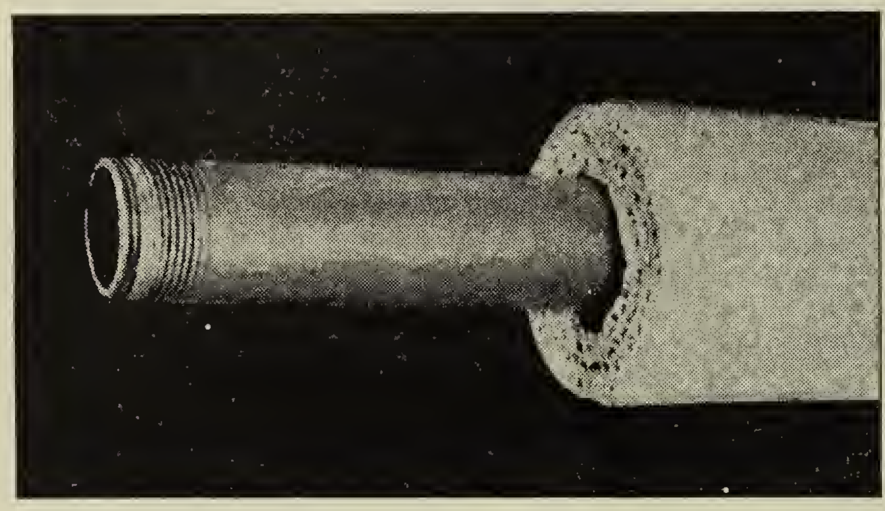
Convection currents produced by a hot-air furnace

Left, over a hot-air shaft; right, over a cold-air intake

molecular action would stop; and not even the scent of a rose could be wafted on the summer's breeze. Everything would be rigidly frozen in the twinkling of an eye, and a degree of desolation unknown to man would envelop the whole earth.

Heat Is Transmitted by Convection, Conduction, and Radiation. Fluids expand when heated and become less dense. By the principle of buoyancy the colder, and hence heavier, surrounding fluids push on the lighter portions and cause them to rise. This results in an upward mass movement in gases and liquids called *thermal convection.* The principle of convection enters significantly into every moment of man's life.

Fluids, such as water and other liquids, and, in particular, gases, are poor conductors of heat when not in motion. Animal bodies are covered with fur not because the hairs in themselves are good heat-insulators, but because the layer of "dead" air which they enclose is a superb insulator. A fur collar turned up about the face and ears on a cold day keeps one comfortable for the same reason. On the other hand, either gases or liquids readily convey heat through convection. A hot radiator or register heats a cold room in a few minutes. If convection in the air about the radiator did not occur, this would be well-nigh impossible, even if the heat were applied hours on end. Indeed, stoves, furnaces, and boilers, which generate heat and power, could scarcely operate were not the principle of convection acting to make a draft in the chimneys to support combustion.



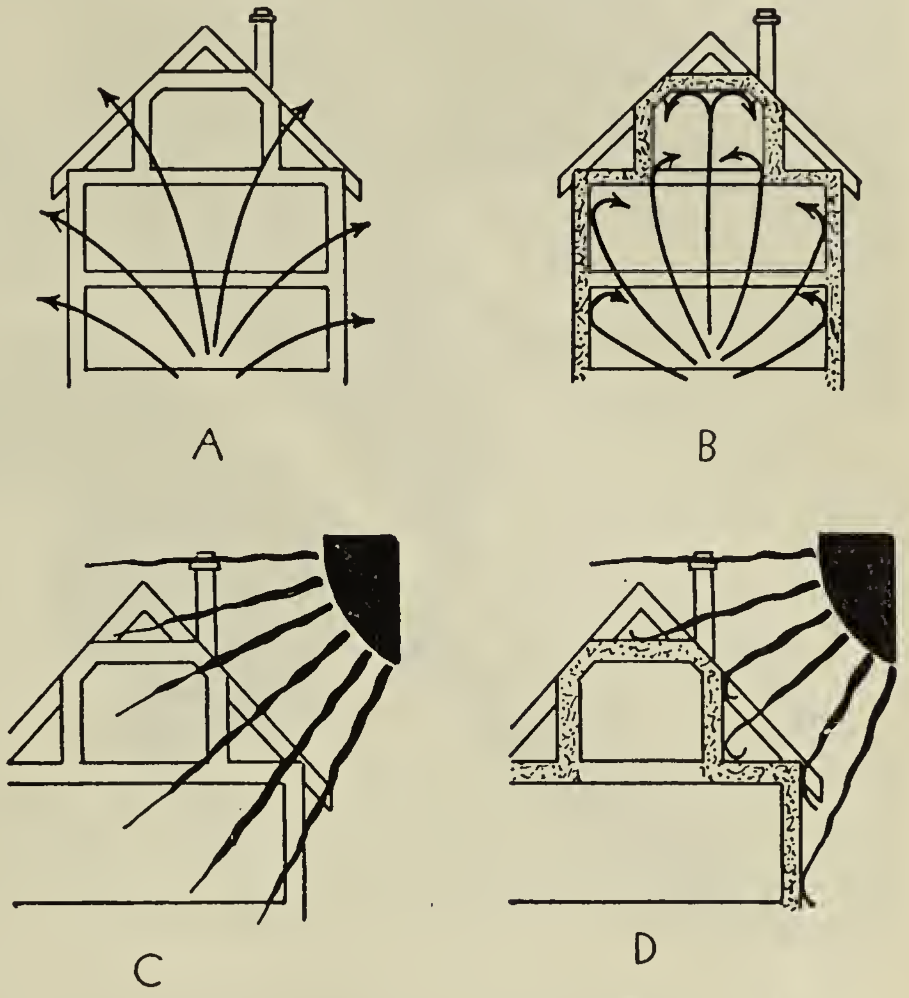
Insulating a pipe

The cellular covering around the pipe creates dead-air spaces, which furnish good insulation

In nature the same principle is manifest on a much grander scale. The air of the atmosphere becomes heated, expands, and is pushed upward by the denser colder air crowding in from below. The convection currents set up in this way become the fundamental consideration in weather changes, as we shall see when we come to that subject. Yet these manifestations are all a matter of molecular action and mass movement due to the different degrees of heat present.

Solids also conduct heat but in a manner different from convection. When the molecules of any portion of an iron bar, for example, are heated, their kinetic energy is proportionately increased and the molecular vibration is speeded up. This increased activity is communicated from molecule to molecule until ultimately the whole bar has its molecules vibrating at the same rate. The temperature of all parts of the bar is then uniform. If any portion of the same bar be cooled, let us say 20°, its molecules are slowed down because they have conveyed their kinetic energy (heat) to the cooling agent, whatever that may have been. The greater molecular energy of the surrounding warmer parts of the bar is now gradually conveyed to the cooler portion. From this action the result is that the colder part is raised in temperature and the formerly warmer parts are lowered in temperature. Uniform temperature is restored at some point between the two extremes. The conduction of heat energy from molecule to molecule in this manner is called *thermal conduction.* Although liquids and gases convey heat to a slight degree by conduction, nevertheless in these fluids convection is the much more important principle.

The fact that solids vary widely in their thermal conductivity is of great value to man. Many substances, such as silver, copper, and aluminum, are known to be good conductors of heat. These materials are used for cooking utensils and other purposes where rapid and efficient conduction of heat is desired. On the other hand, glass, hardwood, and cork are relatively poor thermal conductors. When heat conduction must be reduced, as in the handles of cooking utensils, substances of this nature are used.



The Philip Carey Manufacturing Company

Diagrams to show the effect of insulation

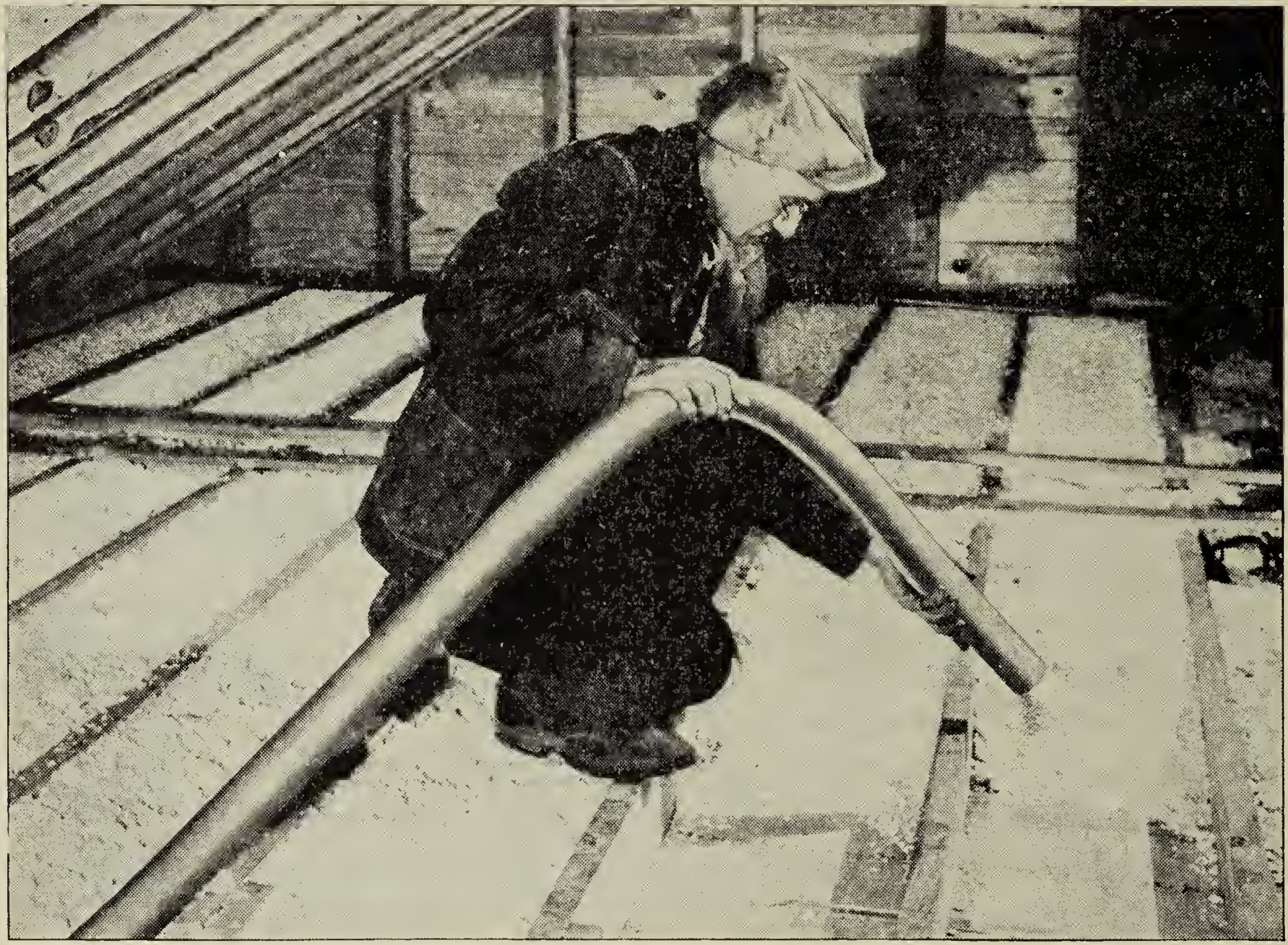
A and *B*, insulation conserves heat; *C* and *D*, insulation protects from the heat of the sun

The amount of heat conducted by a substance is known as its *thermal conductivity.* The thermal conductivity of a substance is the number of calories per second that passes through one square centimeter of a plate of that substance one centimeter thick when there is a difference of 1° C in temperature between the faces of the plate. The relative heat-conducting capacity of some common substances may be clearly seen by comparing the thermal conductivity of the substances given in the following table:

Substance	Thermal Conductivity in Calories per Second	Substance	Thermal Conductivity in Calories per Second
Silver	1.096	Glass	.002
Copper	1.000	Hardwood	.0005
Iron	.670	Cork	.0001
Aluminum	.500		

The better cooking utensils and other devices designed to conduct heat are made of metal. Aluminum and copper are commonly used.

By contrast, the walls of refrigerators and other cold-storage chambers are filled with ground cork, asbestos, diatomaceous earth, or wood pulp, or are built with a dead-air space, which acts as an insulation against the inward conduction of heat. Thermos bottles are made with a vacuum as a heat-insulator, and steam pipes are covered with an asbestos sheathing to prevent thermal loss. Offices and dwelling houses now are being extensively insulated



The Philip Carey Manufacturing Company

Application of insulating material above the ceiling of a house

to hold the heat in during cold weather and to exclude the heat during hot weather.

Molecular energy may also be transmitted from a warmer body to a colder one in the form of radiant-energy waves. The loss of heat in this way is known as thermal radiation. The radiations themselves are not warm, for they may pass from one body to another through a transparent medium, such as air, and raise the temperature of the second body without affecting the temperature of the intervening air through which they pass. It is this radiation effect which causes a closed automobile, when standing in the sun, to become so much warmer on the inside than the surrounding air. In this case visible light rays pass into the passenger compartment through the transparent glass windows. Once inside, the visible light rays impinge upon the interior surfaces and by conversion into heat tend to raise the temperature of the passenger compartment. The warmed interior surfaces now emit long invisible heat radiations. These thermal radiations are not heat waves in the sense that they are warm. They do not warm the interior air of the automobile through which they pass, just as visible solar light does not warm the upper reaches of the clear atmosphere through which it is transmitted on its way in from the sun. But these so-called heat radiations are too long to pass through the glass again, as the energy did when it entered through the windows of the car in the form of shorter waves of visible light. So these thermal radiations collide with the glass or are reflected back to the interior surfaces of the car and are again converted into heat, which raises the temperature of the passenger compartment. In truth the car in this way becomes a sort of radiant-energy trap.

The picture of a green leaf in the bright sunshine may be taken by using an infrared film and filtering out the shorter visible rays. After the picture is printed, the leaf looks white. In this case the film image was formed by the long, thermal infrared rays, which reradiated back from the leaf into the atmosphere. If this radiation did not occur, it is believed that green leaves might frequently be seriously burned by the large amount of solar energy which is absorbed by the green cells and in this way is transformed into heat.

It is a popular fallacy that cold is the opposite of heat. Nothing could be farther from the truth. When a body gets cold, it does so not because cold comes into it, but rather because heat goes out of it. Likewise a cold body gets warm not because cold leaves it, but because heat in the form of increased molecular energy enters. Cold is simply the absence of heat.

Questions for Study

1. How do the foods of a typical meal supply one with energy which has come from the sun?

2. Why are there believed to be tremendous amounts of energy within a single atom?

3. When coal is used for household-heating purposes, what are the forms of energy involved and their sources?

4. When a man drives a stake into the ground with a large sledge hammer, what are the chief energy exchanges involved?

5. What states and forms of energy are involved in the operation of an automobile?

6. In what way is heat related to the daily activities of man?

7. What are the units used by man to measure and to designate quantities and degrees of heat, and what does each mean?

8. How may latent heat be of value to man?

9. How does the heat of vaporization affect the life and the living conditions of man?

10. What are some of your everyday experiences in which the principle of specific heat plays a part?

11. Why does it take more heat to boil water at sea level than at higher altitudes?

12. The city of San Francisco and the city of Denver are about the same distance north of the equator; yet San Francisco has a relatively mild climate with a narrow temperature range, while Denver has a cooler climate with a wide temperature range. What principles of heat could be cited to explain this difference?

13. During a recent hot wave in California an item in the newspaper stated that the Golden Gate Bridge, extending from San Francisco northward across the bay, had increased some ten inches in length, while the San Francisco–Oakland bridge, extending eastward, had increased about twenty-four inches in length. How would you explain this result?

14. Most automobiles are now equipped with a heat-measuring instrument to measure the temperature of the water in the radiator. How do these instruments operate?

15. What are the scientific principles involved in the operation of thermostats?

16. One important requirement in many new homes and other buildings is that they be insulated against heat and cold. What principles are involved in heat insulation?

17. Why is aluminum considered to be a better metal for the manufacture of cooking utensils than iron?

18. How are heat principles involved in the operation of a hot-air heating plant?

19. How are heat principles involved in a steam-heating plant?

20. Why is a hot-water heating system in the home preferable to a hot-air system?

21. How has man's increased knowledge of heat contributed to his better understanding of natural phenomena?

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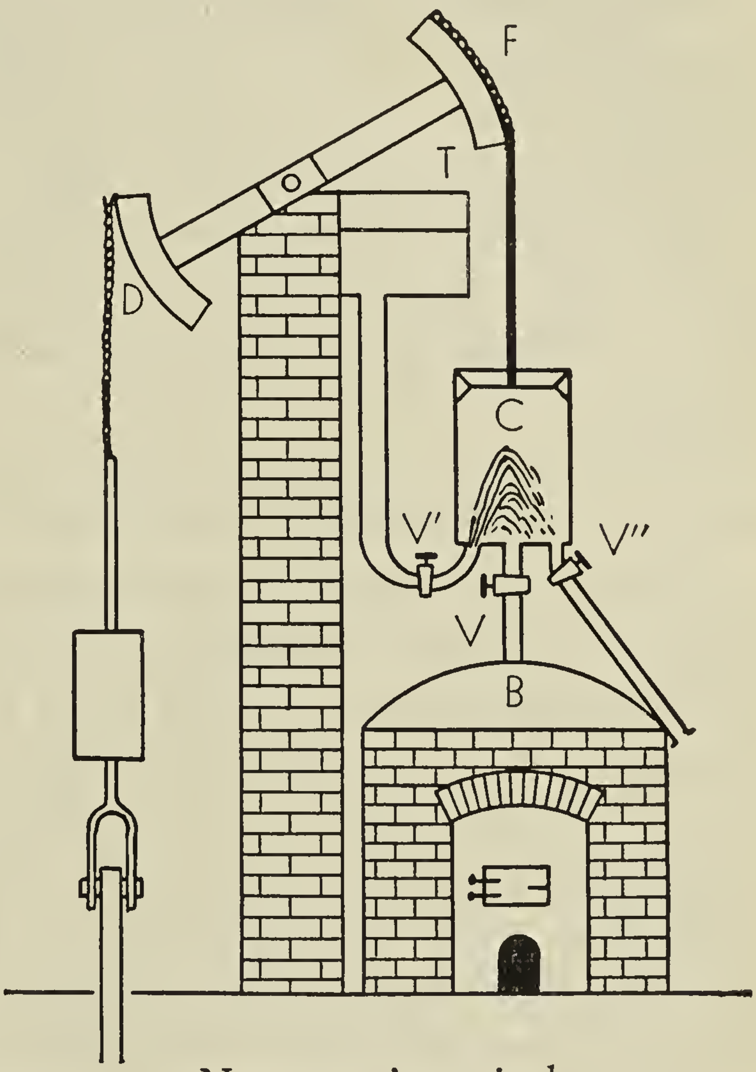
CHAPTER EIGHTEEN

Heat Is Applied in Many Different Ways for the Convenience and Comfort of Living

The First Steam Engines Were Crude Machines. Like many other great inventions, the steam engine had its origin from necessity. When the coal mines of England were first worked, they were known as pit mines. This name arose from the fact that they were worked from the surface downward and in time presented the appearance of huge pits. As the workings were sunk deeper and deeper, water was encountered. It accumulated in the pits and made further progress well-nigh impossible. At first crude pumps worked by man power were brought into use. But these, while affording some relief, were no match for the great floods of water that accumulated in the mines. So men racked their brains just as they do today when brought face to face with a major difficulty.



Newcomen's engine[1]

Little relief was afforded until Thomas Newcomen started to work on the problem. Newcomen succeeded in perfecting an engine that could pump water. As judged by modern standards, it was a crude affair (see the illustration on this page). In this engine steam from the boiler *B* was admitted to the cylinder *C* when the valve *V* was opened. The steam now forced the piston upward till it reached the upper end of the cylinder. At this point the valve *V′* was opened, which admitted cold water from the tank. This condensed the steam, which tended to create a vacuum in the cylinder below the piston. The piston in turn was then forced downward by the atmospheric pressure above. The water in the lower part of the cylinder, admitted from the tank, and the condensed steam, were next drained off by opening the valve V'', and the engine was then ready to initiate a new cycle. The cyclic movement of the piston rod in this manner worked a rocker arm *DF*, which in turn moved the pump rod up and down.

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[1] From *The Boys' Own Book of Great Inventions*, by Darrow and Hylander. By permission of The Macmillan Company, publishers.

This was indeed a crude engine whose speed was snaillike compared with the swiftly shuttling piston rods of the modern steam engine. But it was a mechanical triumph in that it could get water out of the mines faster than the man-operated pumps could do it.

Watt Made an Improved Steam Engine. Aside from its comparatively slow action, Newcomen's engine was very wasteful of fuel. It required a great deal of heat after each condensation to raise again the temperature of the cylinder to that of steam.

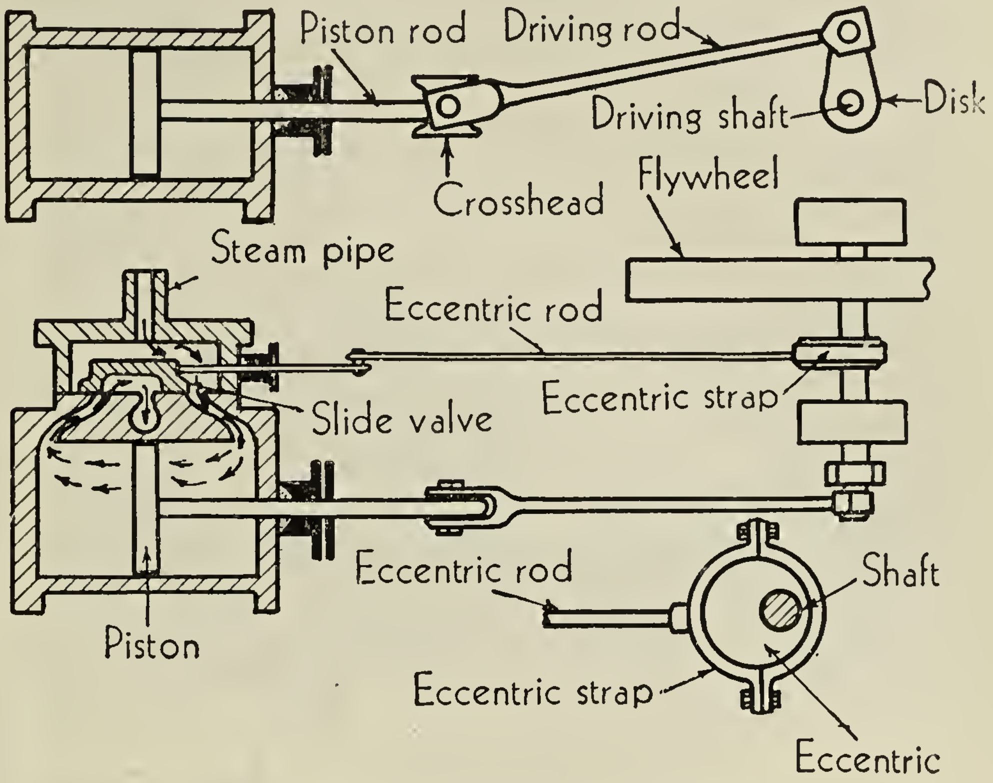
James Watt overcame that difficulty. He was a Scotch instrument-maker, who was one day called upon to repair one of the Newcomen engines which refused to run. He perceived the inefficiency of this type and set to work to improve it. The first work proved of some advantage, but his later improved model not only more than doubled the efficiency of the engine, but introduced the very principle upon which the steam engine operates today.

Watt's highly improved engine dispensed entirely with steam condensation after each forward movement of the piston. He conceived the idea of admitting steam first at one end of the cylinder and then at the other to move the piston back and forth. Just before each movement of the piston, an exhaust valve was opened at the opposite end of the cylinder to let the steam used in the previous stroke escape. It is the sudden outrush of the previously used steam when the exhaust valve is opened that produces the loud puff of the railroad locomotive when starting a train. The diagram on page 293 shows the principles upon which the simple steam engine works.

The eccentric rod is moved back and forth as the eccentric turns on its shaft. This movement of the eccentric rod back and forth slides a valve to and fro against its smoothly ground valve face. The action of the valve both opens the steam-intake pipe for one end of the cylinder and simultaneously opens the exhaust valve for the other end of the cylinder.

In this manner the piston is driven back and forth. The action of the piston is conveyed to the disk through the piston rod, the crosshead, and the driving rod. In this way the driving shaft is made to rotate. If the engine is a stationary one, the driving shaft in most cases turns a flywheel which drives a belt to run other machinery. If the driving shaft is fitted instead with driving wheels, like those of a locomotive, movement in a horizontal direction is produced.

But what, one may ask, is the primary principle underlying the action of the steam engine? In a word, its operation depends upon the effect of heat in increasing the molecular action and hence the bombarding effect of steam molecules. The principle is closely related to Charles's law (p. 174). In reality it would be more appropriate to call the steam engine a *heat* engine.



Principle of the improved steam engine [1]

It has been found that water expands to about 1600 times its original volume when passing from the liquid to the vapor state (see figure on page 294). With the continued application of heat to the boiler and the latter's consequent rise in temperature, more molecules of water evaporate and crowd in between the molecules of steam already formed. The result is that more molecules now bombard a square inch, let us say, of the inner surface of the boiler, and the pressure rises.

As heat continues to be applied, there is a further crowding of the vapor molecules, owing to increased evaporation. Also, as the temperature rises, the kinetic energy of the molecules increases, which likewise results in a heavier bombardment upon the boiler walls. As a consequence, the pressure rises in some instances to two or three hundred pounds per square inch.

When the throttle valve with this high pressure behind it is opened, the molecules of steam rush out into the cylinder, with the result that there is a heavy bombardment of the sides of the cylinder and the piston head. The piston is forced ahead of the steam, and thus motion is produced. This gives in outline the principles upon which the steam engine operates. Since Watt's day many accessory controls and improvements have been added.

The steam engine has multiplied man's available energy many times. The use of the steam engine has changed the whole industrial picture and made possible the mass production of goods in one central manufacturing plant.

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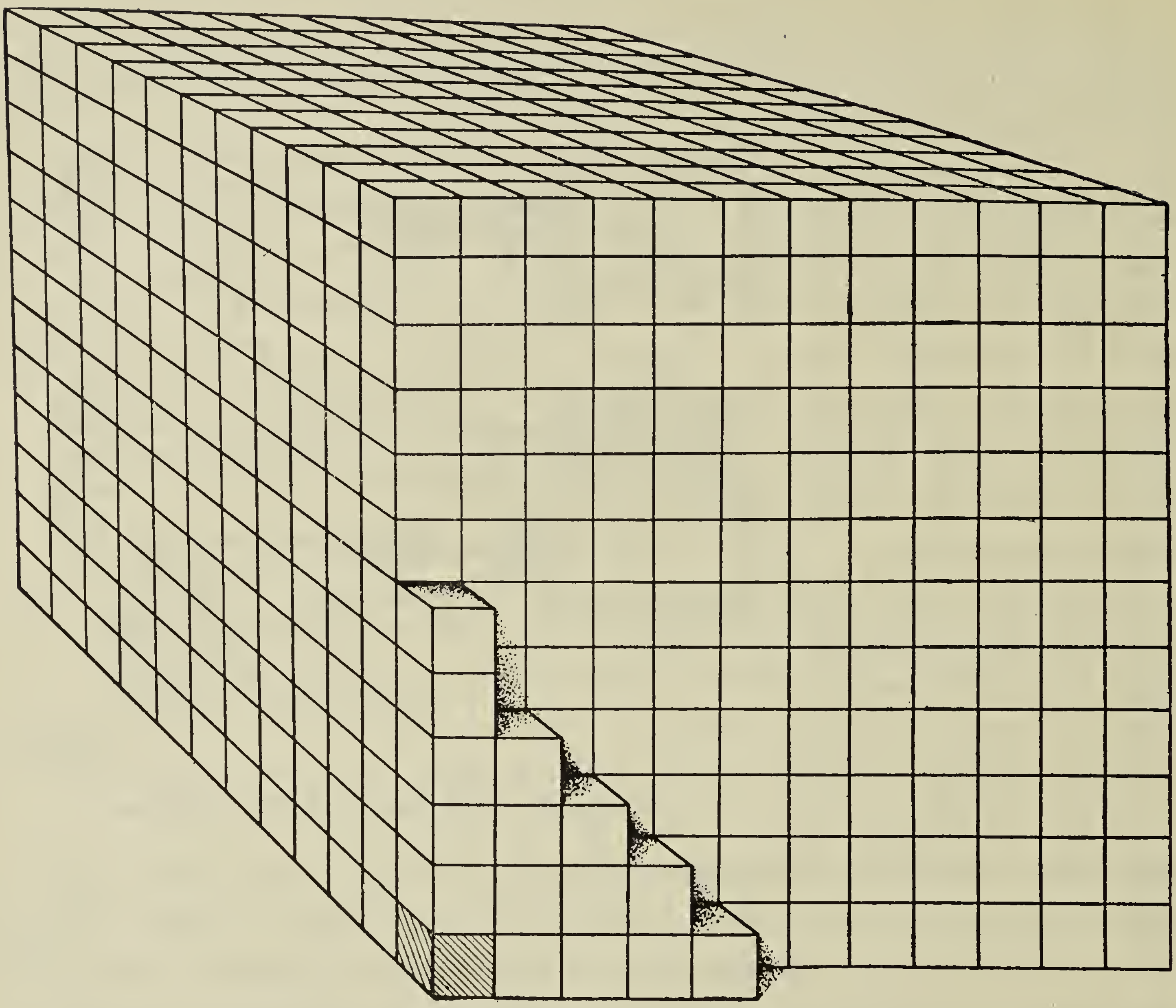
[1] After *The Boy's Own Book of Great Inventions*, by Darrow and Hylander. By permission of The Macmillan Company, publishers.

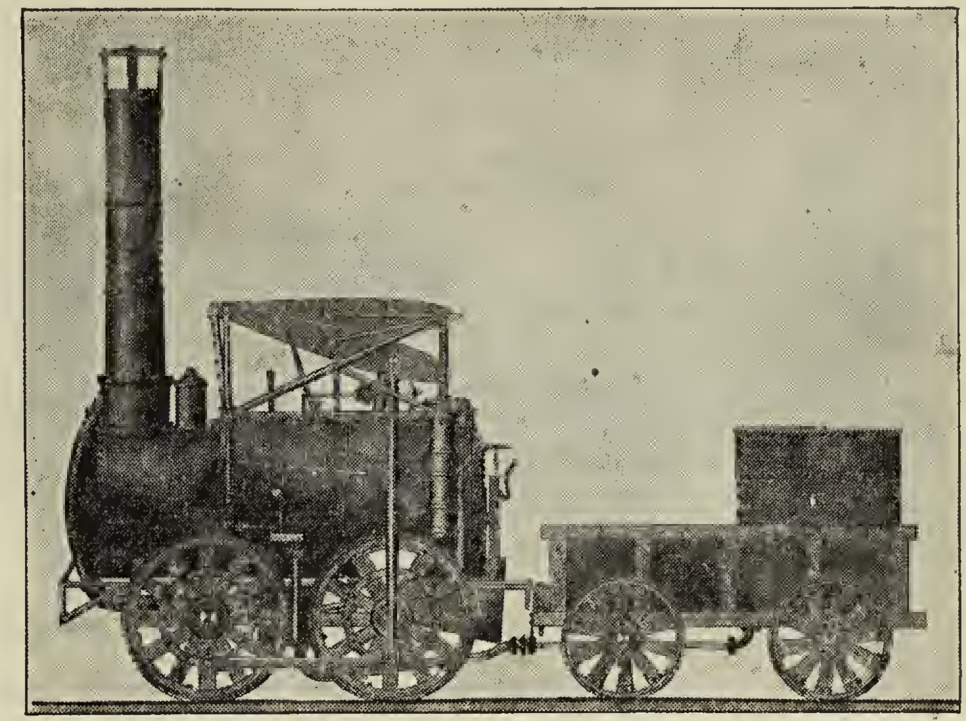


1 cubic inch of water when changed to steam expands to 1600 times its original volume

The steam engine has made a major contribution to American life by solving the problem of transportation. When industrial goods began to be manufactured in quantity, their distribution became a pressing problem; and even before the industrial period, extensive travel in our rapidly expanding young nation had become difficult. The coach and four took too long to carry a person from the Atlantic coast into the heart of the vast domain acquired through the Louisiana Purchase. Indeed, the objection that official representatives of this territory could not travel the long distance from there to the national capital at Washington was one of the main arguments urged against this purchase in the first place.

But into this situation the steam conveyance came. The first locomotive to run in the United States was the *Stourbridge Lion.* With Horatio Allen at the throttle, the engine made its trial trip between Carbondale and Honesdale, Pennsylvania, on August 9, 1829. The intrepid Allen was not without his misgivings, however, for this locomotive, received from England, weighed six tons when it came, instead of three tons, as specified in the order. Allen's emotional reaction as he faced this "monster" is revealed in his own account, written shortly afterward.

> When the time came, and the steam was of the right pressure, and all was ready, I took my position on the platform of the locomotive alone, and with my hand on the throttle-valve handle, said: "If there is any danger in this ride it is not necessary that the life and limbs of more than one be subjected to that danger."
>
> The locomotive, having no train behind it, answered at once to the movement of the hand;—soon the straight line was run over, the curve was reached and passed before there was time to think as to its not being passed safely, and soon I was out of sight in the three mile ride alone in the woods of Pennsylvania. I had never run a locomotive nor any other engine before; I have never run one since.



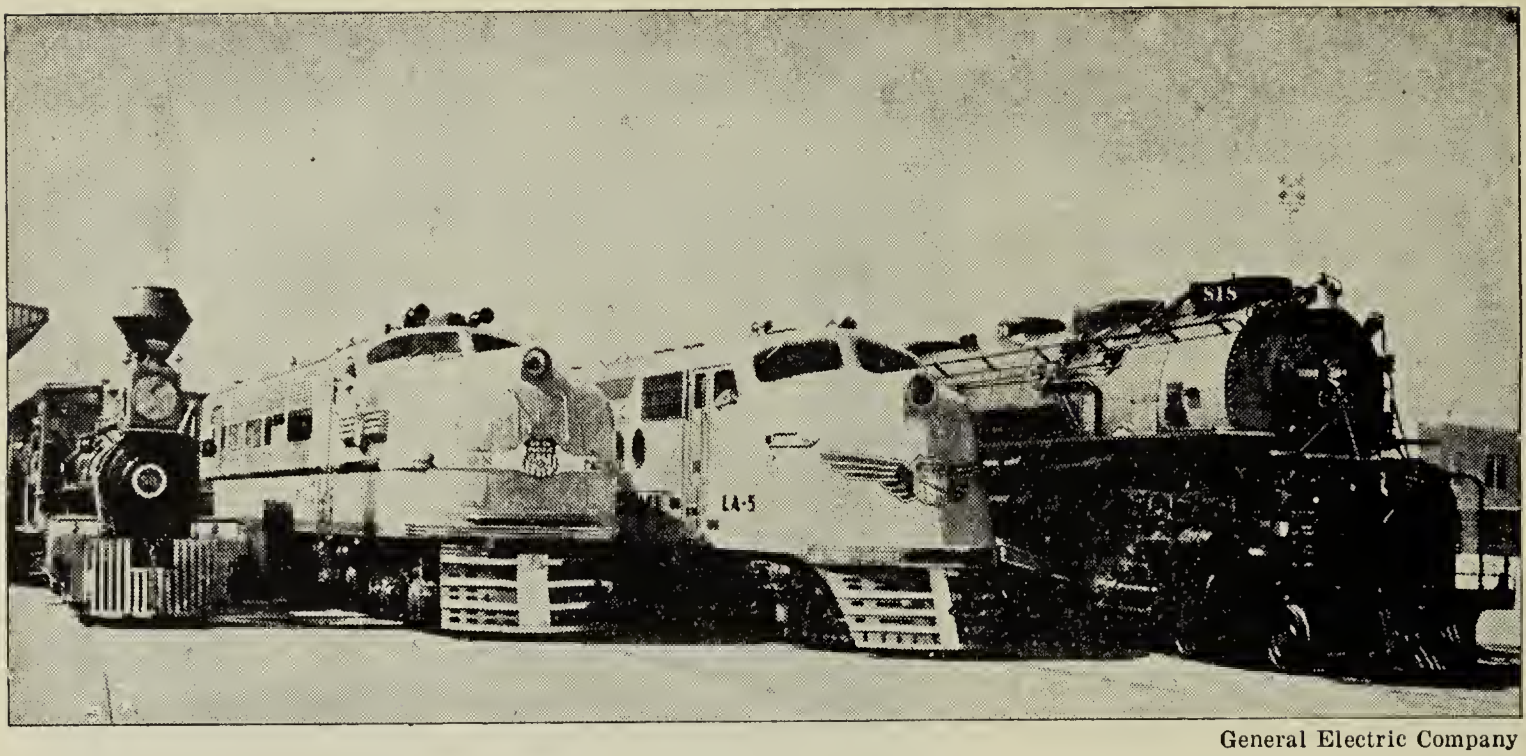
The Delaware and Hudson Railroad Corporation

Stourbridge Lion

It is hard for us to realize the rapidity with which railways were extended and to what extent their equipment grew in both size and numbers. Whereas the *Stourbridge Lion* weighed but six tons, the largest locomotive on exhibit at the World's Fair in New York in 1939 was 140 feet long, weighed 958,000 pounds, and could pull a 1200-ton train at a speed of 100 miles per hour.

Cheap, rapid transportation has been one of the main factors in the growth of the nation. In Washington's time it cost $20 to haul a cord of wood twenty miles, and $5 to haul a barrel of flour 150 miles. The latter charge is at the rate of 46.6 cents per ton-mile. Just before World War II the average charge for hauling freight by the railroads of the country was 0.983 cent per ton-mile, and the cost of individual passenger travel of all classes was 1.84 cents per mile.

Steam turbines have also been perfected. In this type of engine the power is developed by causing a blast of steam to strike against the blades of the rotating part of the turbine. By this contrivance the necessity for stopping and reversing direction at the end of every stroke is obviated, which greatly increases the power efficiency. The principle is exactly the same as that involved in the turning of a windmill by a current of air. In the steam turbine,



General Electric Company

Union Pacific locomotives

Streamlined Diesels in the center

however, the steam is usually under a considerably higher pressure, which makes it very much more powerful.

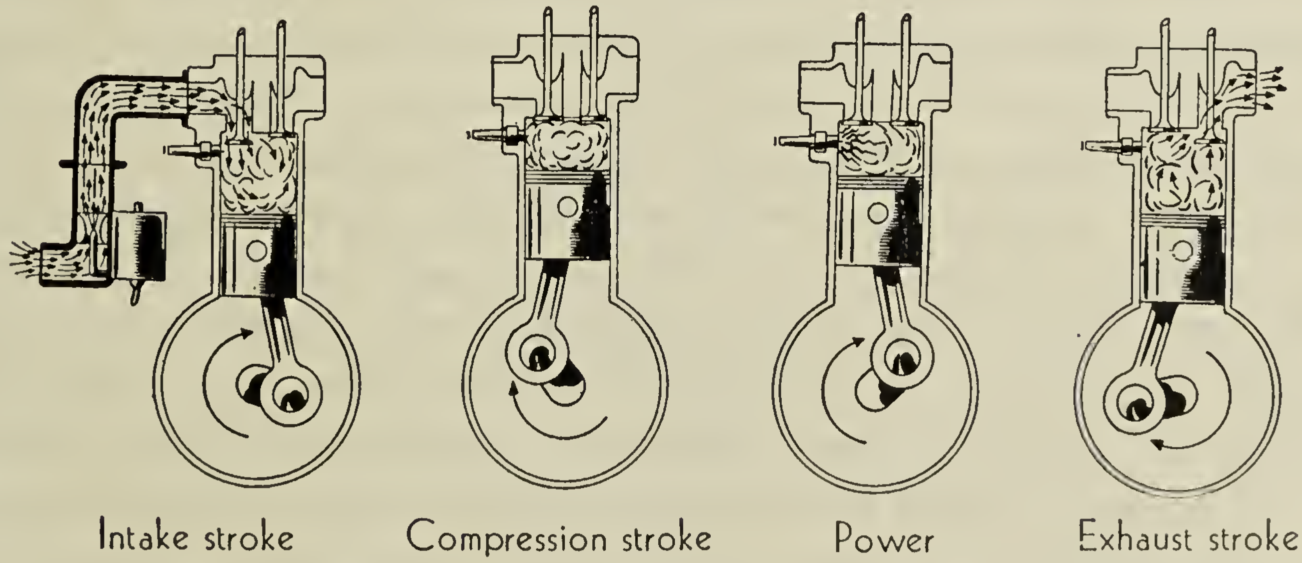
Just recently one railroad built a giant steam-turbine locomotive as an experiment in transportation equipment. This power unit is virtually a steam-generating electric plant on wheels. The huge unit generates 45,000 pounds of steam an hour at a pressure of 1500 pounds to the square inch and drives the main turbine at 12,500 revolutions per minute. The turbine, in turn, drives an electric generator, which develops the current to turn the wheels of the locomotive. This power unit has proved so successful that the company has ordered several more for heavy freight duty.

The Internal-Combustion Engine Furnishes Much of the Power Used Today. For many decades the steam engine and the water wheel have been the chief sources of power. This is still true today in large electric power plants, for the electric generator has to be driven by one or the other of these power-producing machines. Recently, however, a type of engine called the *internal-combustion engine* has come into wide use. Its chief advantages lie in the fact that it uses a highly concentrated fuel, such as gasoline or kerosene, and that combustion, instead of occurring in a firebox, as in the steam engine, takes place within the cylinders themselves. It is for this reason that the adjective *internal* is applied. Automobiles, trucks, motorboats, lighting plants, tractors, graders, airplanes, and often the smaller electric generators, as well as scores of other machines and mechanical devices, are driven by internal-combustion engines. Other advantages of the internal-combustion engine are its relatively light weight in comparison with the power developed, its compactness, and the ease with which it may be attached directly to the appliance or vehicle that it is to operate. Since practically all automobiles are driven by internal-combustion engines, some knowledge of the principles under which these motors work is almost indispensable to the careful, successful driver.

In the internal-combustion engine the pistons are driven by the "kick" of an almost instantaneous combustion which occurs at regular intervals within the cylinders. Consequently the chief considerations to be provided for in the construction of a gasoline motor, for example, are four: the gasoline must be vaporized and mixed with air; it must be conveyed to the cylinders and compressed; it must be ignited; and, lastly, provision must be made for the escape of the waste gases produced by the combustion.

An understanding of the principles underlying rotary motion produced by a gasoline engine can best be gained by a study of diagrams. The carburetor receives the gasoline from the fuel pump and sprays it through a fine jet into the mixing chamber, where it is mixed with air. Ordinarily this mixture is made in the proportions of about 1 pound of gasoline to 15 pounds of air. In other words, each gallon of gasoline, weighing about 7 pounds, must be mixed with about 100 pounds of air. This is about 9000 gallons of air at ordinary room temperature and pressure. So heavy is the consumption of air that when an automobile is traveling 70 miles an hour, the air is rushing in through the air vent of the carburetor at a speed of about 250 miles an hour.

From the mixing chamber the gaseous mixture passes through the "throttle" into the manifold, where it is warmed and distributed. From there it is forced into the cylinders through a set of intake valves. The driver controls the speed of the motor by an accelerator manipulated by the



Diagrams to illustrate the principle of the internal-combustion engine

foot. Pressing down on the accelerator simply opens the "throttle" wider, and this permits more gas to rush into the manifold and through the valves into the cylinders.

Once in the cylinder, the gas must be compressed, both to raise its temperature and to reduce it to a small volume in order that the piston may get the full propulsive force of the explosion. In a single-cylinder gasoline engine this compressive force must be supplied by the momentum of heavy flywheels attached to the driving shaft. In an automobile engine the same result is achieved by increasing the number of cylinders and decreasing somewhat the size of the flywheel. Now, after one cylinder has fired, all the other cylinders in the series fire in a predetermined order. This continuous series of propulsions conveyed to the driving shaft through the pistons and connecting rods keeps the engine running at high speed and with a constant output of power. It also furnishes to each cylinder, after firing, the energy to take in a new supply of gas, compress it, and get ready for its explosion in the next cycle. The more cylinders an engine has, the more propulsions per second the driving shaft will receive; hence the smoother it will run and, with proper cylinder bore, the more power it will deliver. Automobile motors are now made with as many as sixteen cylinders.

The Diesel Engine Promises Much for the Future. A special type of internal-combustion engine destined to come into even larger use than at present is the Diesel motor. This engine works on the same principle as the gasoline motor except that it burns heavier petroleum fuel oils and has neither carburetor nor spark plugs.[1] Instead the oil and air are taken directly into the cylinder through different vents.

In the automobile motor the gasoline-and-air mixture coming from the carburetor is compressed to about one sixth of its original volume before firing. In the Diesel engine, however, the intake of air into the cylinder is compressed to about one sixteenth of its former volume before the explosion occurs. We have found that compressing a gas raises its temperature. With the high compression attained in the Diesel motor the fuel mixture, if it were formed by carburetion, would be heated to a firing temperature long before the piston reached the top of its compression stroke. For were the fuel oil mixed with air, the mixture would begin to burn when compression raised the temperature to about 450° F. But the Diesel compression of 16 to 1 when at its highest point produces a temperature of about 1000° F. Thus the explosion would occur with the piston only part way up on its compression stroke. The result would be either a sharp knock with a great loss of power or the engine might be stopped altogether by the premature explosion. Indeed, Diesel's first engine, built in Germany, exploded and was entirely wrecked at the time of its first trial. The inventor himself was severely injured in the accident.

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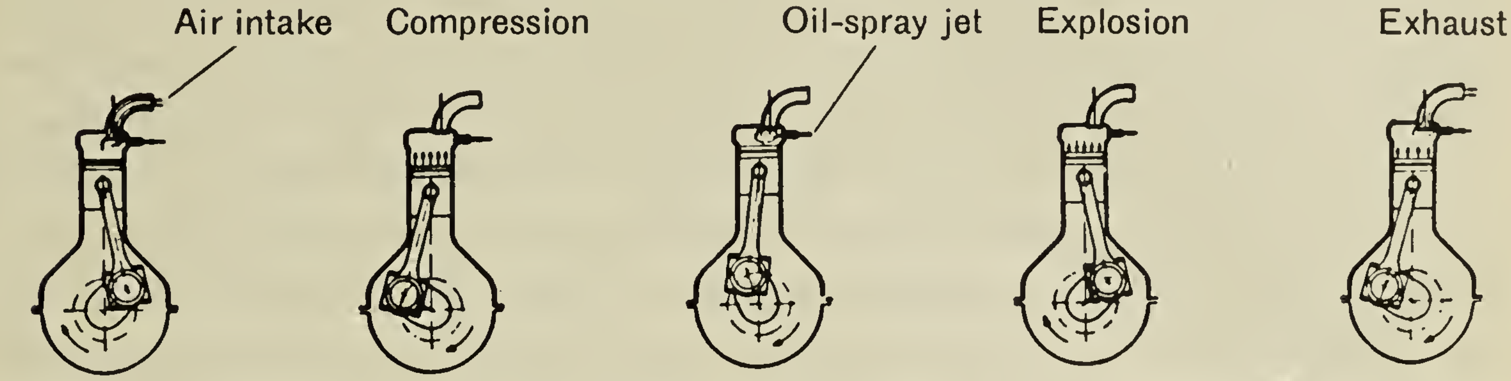
[1] Some Diesel motors are equipped with spark plugs, which are used with gasoline only for the purpose of starting the engine.



General Motors Corporation

The principle of the Diesel motor

To avoid these highly undesirable consequences air only is compressed in the cylinder of the Diesel engine. Then, just as the compression reaches its highest point, the oil jet opens, and a fine spray of fuel oil is forced into the highly compressed, and consequently highly heated, air. The force necessary to drive the oil in through this jet is tremendous. Under usual conditions a pressure of about 15,000 pounds per square inch is needed, and it may reach 20,000 pounds. The oil is driven in quickly, passing through the jet at a speed of about 13 miles per minute.

The fuel oil, driven in under these conditions, immediately explodes without spark-plug ignition and drives the piston downward on its power stroke, just as in the gasoline motor. This oil jet, with its injection of oil against the high igniting pressure, is a most important part of the whole mechanism. In truth, "the heart of the Diesel engine is the *fuel-ignition system.*" The exhaust mechanism and the intake of air preparatory to the next compression are very similar in their action to the action of the gasoline motor except that no carburetor is used.

The great advantage of the Diesel engine is its economy of operation. It burns a heavier oil which does not require a high degree of refinement. But the chief saving comes from the fact that it is more efficient than the gasoline engine, especially when it is developing only a part of its full rated power.

One disadvantage which the Diesel has had is its great weight. This handicap is being largely overcome, however, by improved construction and the use of lighter metals. Progress in this respect is constantly being made.

At present the motive power for many small electric-light plants, ocean-going vessels, tractors, and trucks is being furnished by this type of engine.

Extensive experimentation having for its object the use of Diesel motors in airplanes and automobiles is being carried on. In any comparison of the Diesel engine with the conventional automobile and airplane motor, the lack of an ignition system in the Diesel and its use of cheap fuel oil, which is much less inflammable than the highly explosive gasoline, are important considerations.

The recent most extensive use of this type of motor has been as power units for the so-called streamline trains. These trains are electrically driven, but Diesel engines furnish the generative power. In this field in the United States the Union Pacific, with its *M-10001*, and the Chicago, Burlington, and Quincy, with its *Zephyr*, were pioneers. The *M-10001* is a six-car aluminum train powered by a 900 horsepower Diesel engine. It holds the transcontinental record from Los Angeles to New York—56 hours and 55 minutes. On some stretches of the run a speed of more than 120 miles an hour was attained.

The economic efficiency of the Diesel is shown in that on this trip the whole six-car train traveled 1.6 miles per gallon of fuel oil. The fuel cost averaged less than 2½ cents per mile, and the entire cost for the whole transcontinental distance was only $83. A standard steam train would consume about $300 worth of coal for this distance and would take more than fourteen hours longer to make the trip.

Within the last three years literally dozens of streamline trains of this type have been put into service. Each of the two original pioneer railroads has a whole "fleet" of them, and other roads from the Atlantic to the Pacific have followed the lead. The time seems rapidly approaching when most rail passenger travel will be by these light, economical, speedy, streamline Diesel-powered trains.

On February 4, 1941, the Santa Fe Railroad put into use two new electromotive, Diesel-driven locomotives for main-line freight service. Their chief advantage is in speed and economy of operation. This advance is now being adopted by other roads.

The Invention of Different Power-developing Machines Has Greatly Changed the Means Employed by Man in Private Travel. Ancient and medieval man's mode of private travel on the backs of beasts of burden or in vehicles drawn by them was comparatively slow. Consequently, as soon as power-producing machines were developed, it was quite natural for inventors to begin to wonder about the feasibility of adapting them to both private and public travel.

It was not until about 1825, however, that anything like success was attained in devising a steam-driven carriage. At that time Gurney, an English inventor, constructed a steam vehicle which was further improved and was successfully used as a conveyance for transporting passengers. It seems to have been employed to conduct what would be known today as a bus line. Strange to say, some of the economic objections urged against its introduction sound quite modern, too. It was charged with being a laborsaving device that would make less work for the working class. On at least one occasion a Gurney vehicle was violently assailed. In the words of one of the passengers: "We were attacked by some brutal fellows, who, absurdly enough, imagined we were come to take the bread out of their mouths." In this attack Gurney himself was so badly knocked about that for a time he lost consciousness.

Steam, however, was not a good motive power for public-road vehicles. It required a boiler for generating pressure, and this made the machine unwieldy and a time-consumer. It was not until the internal-combustion gasoline motor for road vehicles was invented in 1874 that the automobile, as we know it today, became a real possibility.

The first machines were crude affairs with solid tires and chain-driven rear axles. They looked more like horse carriages with motors attached than like modern cars. They had but one or two cylinders; hence they required heavy flywheels to complete the three motions of the piston necessary after each explosion to clean the cylinder of combustion by-products and to draw in new gas and compress it ready for firing. Naturally such cars were noisy, and the exhaust could often be heard for half a mile or more. The first attempt to use inflated tires was made in France by the Michelin brothers. Unable to persuade the makers of motorcars even to consider the possibility of putting such fragile things as pneumatic tires on an automobile, they had to buy a car of their own in order to try out the idea. They entered their novelly equipped car in the Paris-Bordeaux race of 1895. The course was seven hundred and thirty-two miles long, and twenty-two inner tubes were used up in the race. Within the space of two or three years most cars were equipped with pneumatic tires.

The foreign designers of cars at that time were not one whit behind the American inventors, if, indeed, they did not excel them; but since we are interested chiefly in the automobile in America, we shall, from this point on, confine ourselves to developments in this country.

The first successful car in the United States was designed and constructed by Charles E. Duryea, a bicycle-maker. While looking after his bicycle exhibit at the Ohio State Fair in 1886, his interest and attention were sharply challenged by an exhibit in the booth next to his. It was a gasoline engine, the first he had ever seen. This motor was a clumsy affair weighing about a ton, although it developed only two horsepower. The carburetor was a tin tank larger than a wash boiler and was stuffed with excelsior. Duryea, however, felt that this engine had great possibilities. Seven years of hard work and experimentation, on his part, marked by failure and success, resulted in a car in 1893 that ran successfully.

Thirty years later this same machine came to light in a barn in Springfield, Massachusetts, covered with dirt, its metal parts thick with rust, and its leather dashboard stiff and hard. The National Museum was immediately notified and, disheveled as it is, it now proudly heads the line of historic automobiles there.[1]

Elwood Haynes was another pioneer in car-designing in the United States. In 1890 he was a producer of oil and gas, and this enterprise required him to travel constantly with horse and buggy. This method of travel was too slow for him. Not being able to find a faster means of conveyance, he set out to build one of his own. He later was joined by other men. As the work progressed, their interest grew, and their efforts were rewarded, on July 1, 1894, by a car that ran successfully. Like Duryea's car, it had solid tires, and a straight horizontal handle for a steering device. To avoid the curious crowd, Haynes and his associate, Apperson, pulled the car three or four miles out into the country behind a horse-drawn vehicle, cranked the engine, and got in. When Haynes threw in the clutch the car started, and the two delighted men literally "flew" for the distance of a mile and a half at an estimated speed of six or seven miles an hour. They then turned the car around and drove all the way to Haynes's home in Kokomo, Indiana, where they had been doing their work. Haynes was now so absorbed with his new car that he abandoned his oil and gas business altogether and from that time on devoted his efforts to the commercial possibilities of his new horseless carriage. By 1898 the Haynes-Apperson Automobile Company turned out fifty cars despite the warnings of the skeptical to the effect that "the horseless carriage was only a plaything for the wealthy."

Other manufacturers entered the field, and refinements, together with accessories, followed rapidly. More cylinders were added; kerosene lights were displaced by carbide headlights, and these, in turn, by the electric-lighting system; tires were improved and enlarged to make riding easier; demountable rims were provided, and then extra wheels were introduced as a matter of convenience; the self-starter was invented, which eliminated the exasperating and exhausting labor of cranking when the motor was cold; automatic gearshifts have been perfected; power and consequently possible

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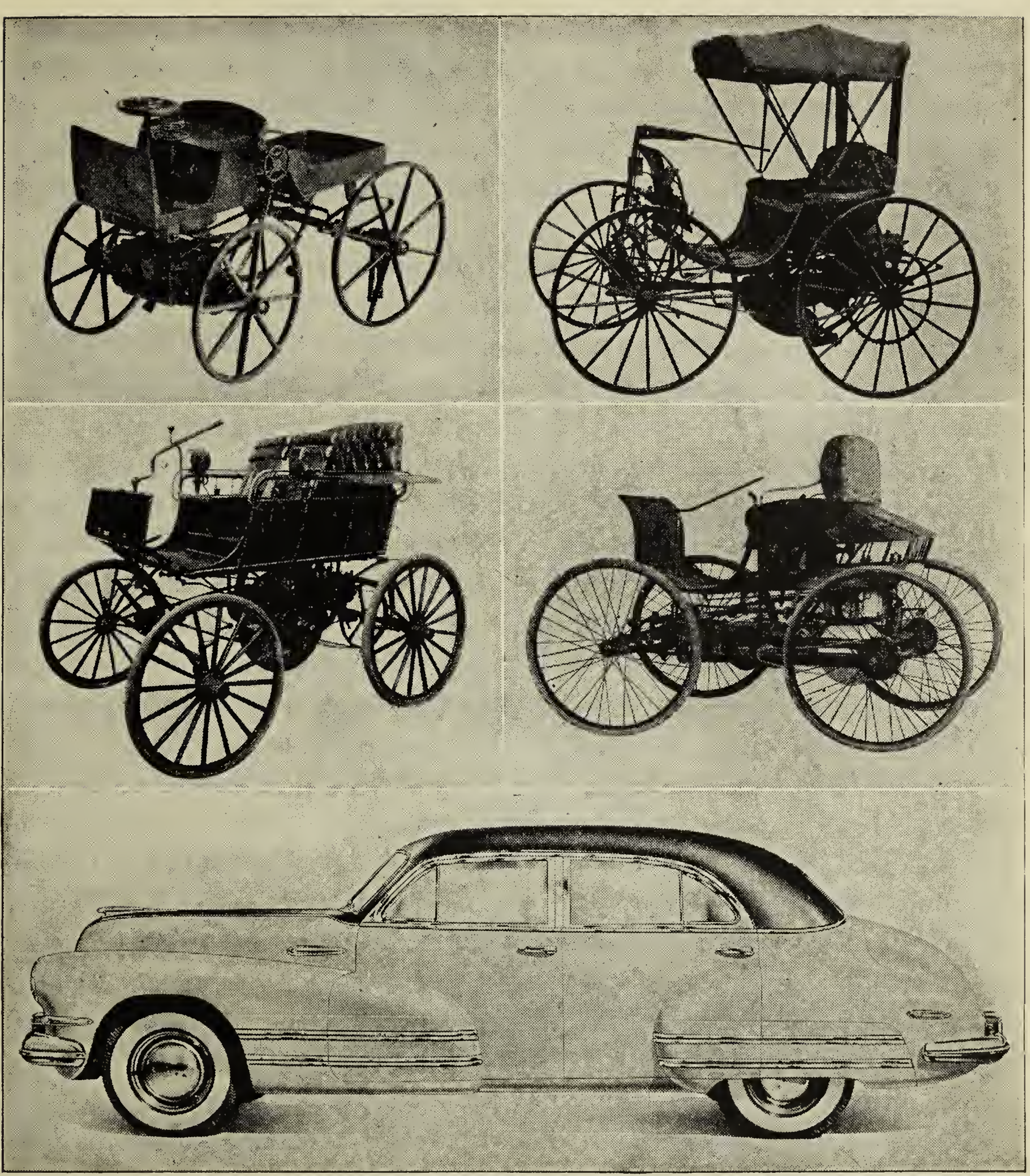
[1] Carl W. Mitman, "The Beginning of the Mechanical Transport Era in America," *Annual Report of the Smithsonian Institution*, p. 555 (1929).



Smithsonian Institution; Buick Motor Division

Early and late types of automobiles

Top, the Selden model and the Duryea of 1892; middle, the Olds of 1896 and the Haynes of 1893; bottom, a 1942 model

speed have been greatly increased; closed bodies were designed, thereby adding materially to the comfort of both summer and winter driving; and lastly, streamline bodies have added greatly to the beauty of the automobile, as well as to economy of operation.

The public demand grew apace with these improvements, and this made mass production possible. With reduced cost and dependable performance the automobile passed quickly from the status of a "plaything for the wealthy" to a business and pleasure-giving necessity. As a result the automobile has become a permanent part of American life. Just before the Office of Production Management put drastic restrictions on the manufacture of automobiles for private use, it was estimated that there were 32,000,000 cars and trucks registered in the United States.

Electrical Refrigeration Has Come to Be an Important Adjunct to Modern Home Life. When a liquid vaporizes, much heat is involved in the process. For instance, about five hundred and thirty-six calories are required to break down the cohesion between the molecules in a gram of water and transform the liquid into a gas. Other liquids require different amounts of heat to effect the same change. Moreover, another consideration, and an absolutely essential one, is that all the heat involved in this transformation disappears as sensible heat and takes the condition of insensible, or latent, heat of vaporization. It is upon this principle that the mechanical refrigerator depends.

To trace the essential parts of one type of artificial refrigerating system, one may begin at the compressor. This is simply a gas pump (usually motor-driven) which receives the gas from the refrigerating coils and compresses it into a high-pressure line that leads to the condenser coils. As the gas is compressed, its molecules are driven closer together, and it simultaneously becomes heated. If now this highly condensed gas be cooled to remove the heat imparted to it through the work of compression, it will liquefy. Cooling is accomplished in different ways. In some of the larger plants it is effected by a stream of cold water which circulates about the coiled pipes of the condenser; in other instances it is cooled by a motor-driven air fan. In some of the more recent types of home-refrigerating units the condenser pipes are formed by two thin sheets of corrugated steel electrically welded together. The compressed gas in its course then follows the multitudinous pathways provided by these corrugations. This platelike condenser offers so much surface that an adequate degree of cooling is achieved by the air of the room circulating about it as convection currents.

From the condenser pipes the liquefied gas collects in a reservoir at the bottom of the condenser. From there it is forced on by the pressure from behind toward the refrigerating compartment. The liquid enters this compartment by way of a controlled expansion valve, through which it trickles into a system of coiled pipes. As the liquid under pressure is pushed through the valve into the coils, it enters a region of low pressure because of the action of the compressor. With the pressure suddenly removed, the incoming liquid rapidly vaporizes. The heat necessary to effect this transformation is drawn

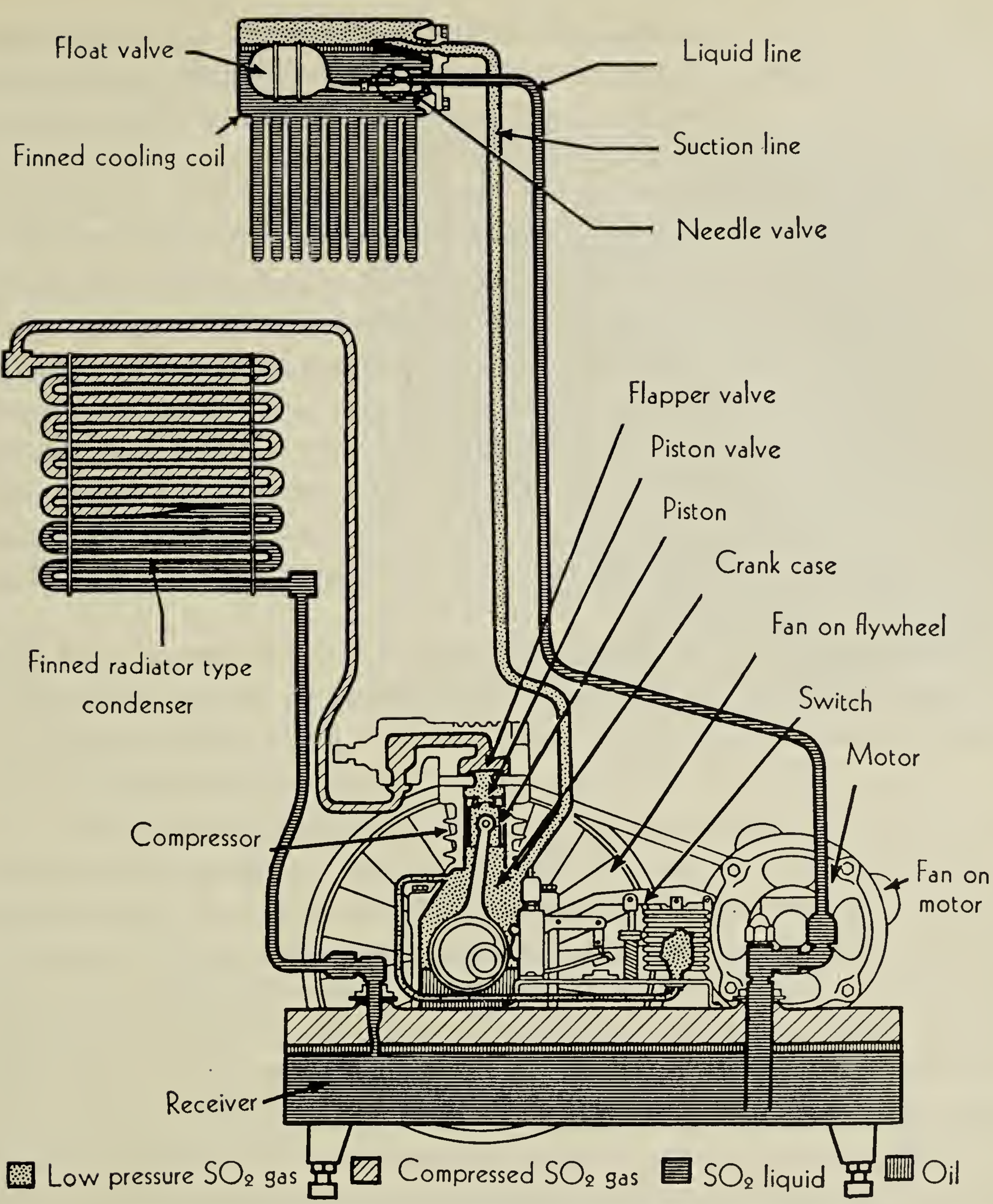

Float valve
Finned cooling coil
Liquid line
Suction line
Needle valve
Flapper valve
Piston valve
Piston
Crank case
Fan on flywheel
Switch
Motor
Fan on motor
Finned radiator type condenser
Compressor
Receiver
▩ Low pressure SO_2 gas
▨ Compressed SO_2 gas
▤ SO_2 liquid
▥ Oil

Diagram to illustrate the principle of an electric refrigerator

from the air, sides, and trays of the refrigerating compartment and takes the state of latent heat of vaporization.

Since the walls of the refrigerating compartment are heavily insulated with dead-air spaces and non-heat-conducting substances, the cooling temperatures within are maintained at a very low cost. Manual controls are provided to regulate the thermostat so as to give any degree of refrigeration desired. To secure subfreezing temperatures for making cubes of ice and ice cream and for preserving frozen foods, a small low-temperature chamber is constructed within the helix of the refrigerating coils.

The gas used in a mechanical refrigerator should be one with a high critical temperature; that is, the temperature at which it will liquefy under pressure should be high. If it possesses this property, a temperature below this point can easily be realized in the cooled condenser coils, and condensation will follow. Sulfur dioxide has a critical temperature of 155.4° C, and ammonia one of 130° C. For this reason these gases have been widely used in mechanical refrigerators. More recently other gases having a high critical temperature are being employed by electric-refrigerator manufacturing companies.

Refrigerated display cases and cold-storage rooms in food stores and cold-storage plants are cooled by means of brine pipes. These brine pipes usually carry a strong solution of calcium chloride. The brine is chilled by a refrigerating unit similar to the one already described for home purposes except that it is larger. By varying the temperature of the brine and regulating the number of pipe coils in the refrigerated space, almost any temperature desired may be obtained.

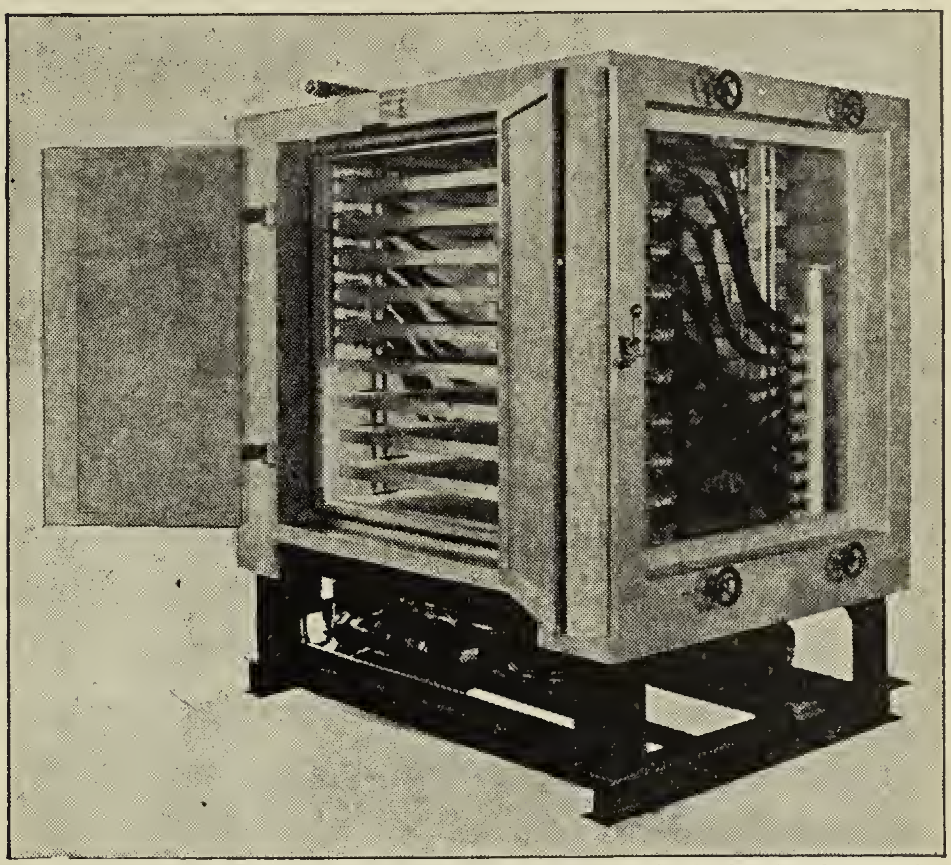
Quick Freezing Is Becoming Important for the Preservation of Many Perishable Foods. The principle of refrigeration in connection with food preservation has been known for many years. It first came into practical use about 1880 in the shipment of meats from Australia to Great Britain. At the outset the foods were preserved under moderately low temperatures.

During the past ten years refrigeration to very low temperatures has been employed in preserving and transporting perishable foods. In this method the foods are frozen solid and are not thawed again until they are to be used. The chief principle upon which the success of this process depends is a very rapid freezing. When vegetables and fruits are congealed at relatively high temperatures, they freeze slowly, large ice crystals are formed within the tissues, proteins may be coagulated, and the result is an undesirable product, if not one wholly unfitted for use. But by employing very low temperatures, say from − 25° to − 30° F, the food to be preserved is frozen very quickly. Thus only very tiny ice crystals are formed, the proteins remain intact, and the quality of the product is but slightly, if at all, impaired.

In the case of some foods the quality is actually improved by quick freezing and subsequent storage at low temperatures. Careful investigation has shown that the tenderness of Grade B sirloin beefsteak was increased approximately 20 per cent after being frozen in this manner and stored one week at 0° F.

The vitamin content, an important consideration in any food selection, is also found not to be affected by this method of preservation. Dr. Carl Fellers, research professor of horticulture at Massachusetts State College, declares of frosted foods, "As we have found them in the retail store they are fully as high in food values, including all the vitamins, as the freshest foods purchased on the market and cooked in the home."

The bacterial content has also been found to be reduced by frosting and storage. Berries showed a bacterial reduction of from 90 to 99 per cent after one year of storage at 15° F; and frosted hamburger steak after storage one month showed a reduction of 84 per cent in its bacterial count.



Birdseye-Carrier Corporation

Multiple-plate froster

Frosted foods were put on the market by the largest company now dealing in this commodity in the spring of 1930. They were offered in one New England city as a trial to see how they would be received. They met with immediate favor, and the demand has constantly grown. Meats of all kinds, strawberries, loganberries, raspberries, cherries, asparagus, green beans, peas, and a variety of poultry, as well as many other foods, are being preserved and shipped in the frosted state. When maintained at the proper low temperature, these products are said to keep almost indefinitely. Raspberries frozen in Oregon were found to be in perfect condition a year later and, when thawed for use, could not be distinguished from fresh ones.

The quick-freezing plan of preserving foods has had an almost phenomenal growth during the past thirteen years. Each year the leading food company in this business has found it necessary to step up its production from 50 to 60 per cent over that of the preceding year. One farm in New Jersey has been established especially for the production of vegetables for frosting. It is a vast domain of 25,000 acres. There one can watch a battery of a hundred tractors tending the land, an army of 3000 employees going about their assigned tasks, and a squadron of six airplanes gliding over the vegetable fields dusting and spraying as a safeguard against insects and plant diseases. To meet the market demand it has been necessary to start freezing far south in the spring and move northward as crops mature. Preserving by this method begins along the Rio

Grande in late winter or early spring and ends with the close of the season far north in Maine, Canada, and the Pacific Northwest.

According to estimates of the volume of the growing industry, about 273,000,000 pounds of foods were frosted in 1938. The total pack in 1939 mounted to about 480,000,000 pounds.

When prepared for freezing, the waste parts of the products, such as bone, scales, outside leaves, and hulls, are removed. The food is packed in containers ready for the kitchen, which means that only the edible parts are shipped. This results in a great saving in freight charges, and it places the product in the hands of the consumer at but a nominal increase over the price that food of equal quality would cost when handled by the old methods.

The declaration by Frederick the Great that "an army, like a serpent, travels on its stomach" has been fully exemplified during the second World War. Food is also an indispensable element in the success of men and women engaged in more constructive pursuits than waging war. As one writer has put it, "It seems clear that man's diet, in its evolution, has paralleled his mental and cultural development." The annual food bill in the United States is approximately $22,500,000,000. Of this amount about $16,500,000,000 worth is perishable food. This gives some idea of the possibilities of frosted foods. One leader in this field declares, "In view of man's primary desire to live and multiply it would not be surprising if the latest development in food preservation . . . might become the basis for a great new industry. . . ."

Recently in many towns and cities local freezing and refrigeration plants are being established. In these plants meats and vegetables directly from the farm and garden may be frozen by the management in a special low-temperature freezing room and then be stored by the owner of these products in refrigerated lockers which may be rented for that purpose. Thus a continuous supply of fresh meats and vegetables is made available throughout the whole year to the people of that vicinity at a minimum cost.

Like every new industry, too, frosted foods are producing industrial and economic repercussions. The canning industry is watching with deep concern the rise of this new industry. Some of the companies are protecting themselves against loss from this source by setting up freezing plants of their own. The farmers too are becoming alarmed in some regions. The mounting pack of frosted foods is seriously cutting into the early vegetable market demand; and the early crops in this field are the most profitable. In one state the vegetable-growers have complained against the government research which is being carried on in connection with frosted foods. They contend that the industry is cutting the very props from under their largest source of income—

early fresh vegetables. Hence widespread and far-reaching economic adjustments apparently must be made if the industry continues to expand, as it doubtless will.

Air-Conditioning Adds to Comfort, Health, and Efficiency. Elsworth Huntington, well-known geographer, has shown in his *Civilization and Climate* that the temperature and humidity conditions under which students and factory hands work materially influence the output of their efforts. For instance, both English and mathematics classes at the United States Naval Academy did much better work in the fall and spring of the year, when the relative humidity and temperature conditions were nearest the optimum of from 40 to 60 per cent and 65° to 70° F, respectively, than they did during midsummer and midwinter, when the mean of these atmospheric factors was less favorable. Moreover, when cigar-makers in Florida worked under proper air conditions, they increased considerably the number of cigars made in a day. Likewise, the resistance of the individual to certain pathogenic microorganisms, especially those of the lungs, throat, and nasal passages, is known to be affected to some extent by the kind of air that he breathes. For these reasons, as well as considerations of bodily comfort, air-conditioning, as it is called, is coming to be an item of scientific importance.

Air-conditioning has been defined as "the simultaneous control of the temperature, humidity, movement, and purity of our surrounding air to produce the most healthful environment in which to live."[1] The demand for such conditioning did not arise, however, out of considerations for human comfort. It arose from the needs of industry. In 1902 a Brooklyn lithographer, working near the ocean, was greatly troubled with the excess of atmospheric moisture which he encountered. He appealed to a manufacturing firm to help him in his difficulty, and from their response air-conditioning has developed.

Air-conditioning has become of great economic importance, particularly to those industries whose products are affected by weather conditions. These are represented, for example, by "the textile industries, including rayon, which could not be manufactured successfully without it; all parts of the tobacco industry, such as in the manufacture of cigars and cigarettes; the printing and lithographing industry; the manufacturing and processing of paper and paper products; the manufacture of chocolate and confectionery; the manufacture of gelatin products, such as capsules and photographic films —in fact by a long list of over 100 different industries."[2]

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[1] C. W. Ott, *Essential Features of Comfort Air Conditioning*, p. 13. (1934)

[2] W. H. Carrier, "Air Conditioning in Relation to Industrial Hygiene," *Industrial Medicine*, September, 1938.

The first office building to be air-conditioned was the Milam building in San Antonio, Texas, in 1929. This venture proved to be so successful that leading builders throughout the country have adopted air-conditioning. The movement has spread to include department stores, hotels, restaurants, theaters, busses, broadcasting studios, steamships, hospitals, banks, and railway passenger cars. There are now in operation on American railroads over ten thousand air-conditioned coaches and Pullman cars.

More than 200,000 cubic feet of conditioned air is supplied to the Hall of the House of Representatives and to the Senate Chamber in Washington, D.C., every minute when these bodies are in session. In other departmental suites of the United States Capitol, too, the scientific control of the air is said to make "every day a good day."

The world's deepest mine is the famous Robinson Deep Mine near Johannesburg, South Africa. The lowest point in the mine has a vertical depth of 8380 feet, or slightly more than a mile and a half. Owing to the compression effects of the air and the surrounding rocks and the moisture encountered, the miners who work in this gold mine toil in temperatures of 85° to 90° F and a relative humidity of from 90 to 100 per cent. A legal requirement compels the operators to wash down the walls of the mine after each blast, and this too adds to the humidity. Under such extreme conditions the physical exertion involved in ordinary labor becomes very trying. The mine gave promise of very profitable workings at greater depth, provided the problem of the highly unfavorable working atmosphere could be solved. Accordingly air-conditioning was installed. Now 400,000 cubic feet of cooled, dehumidified air is poured into this mine each minute. Altogether the equipment has a cooling effect equal to the melting of 4,000,000 pounds of ice each 24-hour period.

The first experimental air-conditioned railroad dining car was fitted up in 1929. The results were so gratifying that the plan was extended to Pullman cars also. In May, 1931, one of the leading roads operating between New York City and Washington instituted the first completely air-conditioned train. The response on the part of the traveling public was so immediate that two months later a second air-conditioned train was added. During that summer of otherwise stagnant business the passenger traffic between these two points on this particular road increased 600 per cent. By the summer of 1932 approximately two hundred air-conditioned cars were either operated or contracted for by the leading railroads of the country. Now practically every main-line, through passenger train in the country is air-conditioned, and the pleasure and comfort of travel, particularly in hot weather, have been almost immeasurably increased.

The air-conditioning movement is not confined to the United States, where it began. It has spread to other lands. The leading manufacturer of this equipment recently reported installations in over ninety-nine different foreign countries.

The term *air-conditioning* has been greatly abused and misapplied. This has arisen from lack of knowledge in some quarters and from misrepresentation in others. Some buildings with nothing but a fan to circulate the warm air have been described as being air-conditioned; other so-called air-conditioned buildings have only a humidifying provision. None of these buildings from a heating and ventilating engineer's understanding of the term is air-conditioned.

True air-conditioning from a technical standpoint involves four principal elements. It provides for (1) controlling the temperature of the incoming air as desired, (2) regulating the humidity, (3) filtering the air to remove dust, odors, or fumes, and (4) distributing the conditioned air so as to provide proper ventilation without creating undesirable drafts.

Fundamentally the science of air-conditioning rests upon very important atmospheric relationships. These relationships have to do principally with the conditions of air temperature and relative humidity. From the point of view of human comfort, it has been found that saturated air at 65° F *feels* precisely as warm as air at 72° which has a relative humidity of only 10 per cent; or that saturated air at 80° F feels as hot as air at 100° when the relative humidity has dropped to 10 per cent. In the first instance there is a difference in temperature of 7° and in the latter a difference of 20°. Yet the sensation is the same in each case. These results were obtained when the air had a linear motion of about 15 feet per minute. Sensible and insensible heat as affected by condensation and evaporation are also important factors to be considered. When one remembers that in the conversion of one ounce of water into vapor 15,195 calories of sensible heat are rendered insensible in the form of latent heat of vaporization, it becomes evident at once just how important these factors are.

Air-conditioning seems to reduce accidents. At the Morro Velho gold mine in Brazil twenty fatal accidents occurred in sixteen months before the installation of an air-conditioning system. During the sixteen months following installation, only six accidents occurred, while at the same time the output increased 13 per cent. Men who are comfortable as they work seem to be more alert mentally and physically.

Air-conditioning apparently contributes to the health of workers, though there is some disagreement on this point. The Metropolitan Life Insurance Company states that the installation of an air-conditioning system has shown no "measurable effects on the incidence or duration of absences for upper respiratory infections or of nonrespiratory illness." On the other hand, the *Los Angeles Times*, the largest newspaper in the city, with approximately 1100 employees, believes that air-conditioning does make a difference. For instance, they have an employees' mutual-sick-benefit organization whose funds are provided for sick workers by the employees themselves. Assessments for this fund during the first year after air-conditioning was installed dropped to 46 per cent less than for any one year during the previous ten. An office building in Lincoln, Nebraska, reports an improvement of 41 per cent in employee loss of time due to illness since the installation of air-conditioning. In the Robinson Deep Mine, already mentioned, the incidence of pneumonia among the miners the first year after air-conditioning was installed dropped more than 40 per cent under the pneumonia rate in a neighboring mine not air-conditioned but operated by the same company. Doubtless the figures above, because of the brief time that they cover, must be taken with some reservation. W. H. Carrier emphasizes the importance of air-conditioning in an industrial situation where dust conditions are extreme:

> Prior to the advent of air conditioning, tobacco stemming rooms had never been humidified. Not only was there a loss from the breakage of the leaf in process, but the dust conditions were the most terrible that could be imagined. You could not see half the length of the room. It was like being in a dust storm. A person who was not accustomed to it could hardly go into the room even with a respirator. The operators worked with handkerchiefs tied over their mouths which they used as home-made respirators. Air conditioning was installed to remove the dust through high humidities and rapid air change. As a result, the room was clear and operatives could work in it without any discomfort or ill effects; moreover, loss by breakage was sufficiently reduced to pay for the installation![1]

Dr. Leslie Gay of the Johns Hopkins Hospital experimented with an air-conditioned ward in the hospital as a relief refuge for hay-fever and pollen-asthma patients. Glass slides with an adhesive preparation on them caught from 10 to 30 ragweed pollen grains per square centimeter per day in both that ward and an adjacent one. When the room was closed and air-conditioned, all pollen was removed from its atmosphere; but pollen continued to be sown generously by the breezes in the control ward. It is reported that patients suffering from pollen hay fever experienced relief within fifteen minutes after being transferred to the experimental room; and within an hour their symptoms had entirely subsided. Pollen-asthma patients responded

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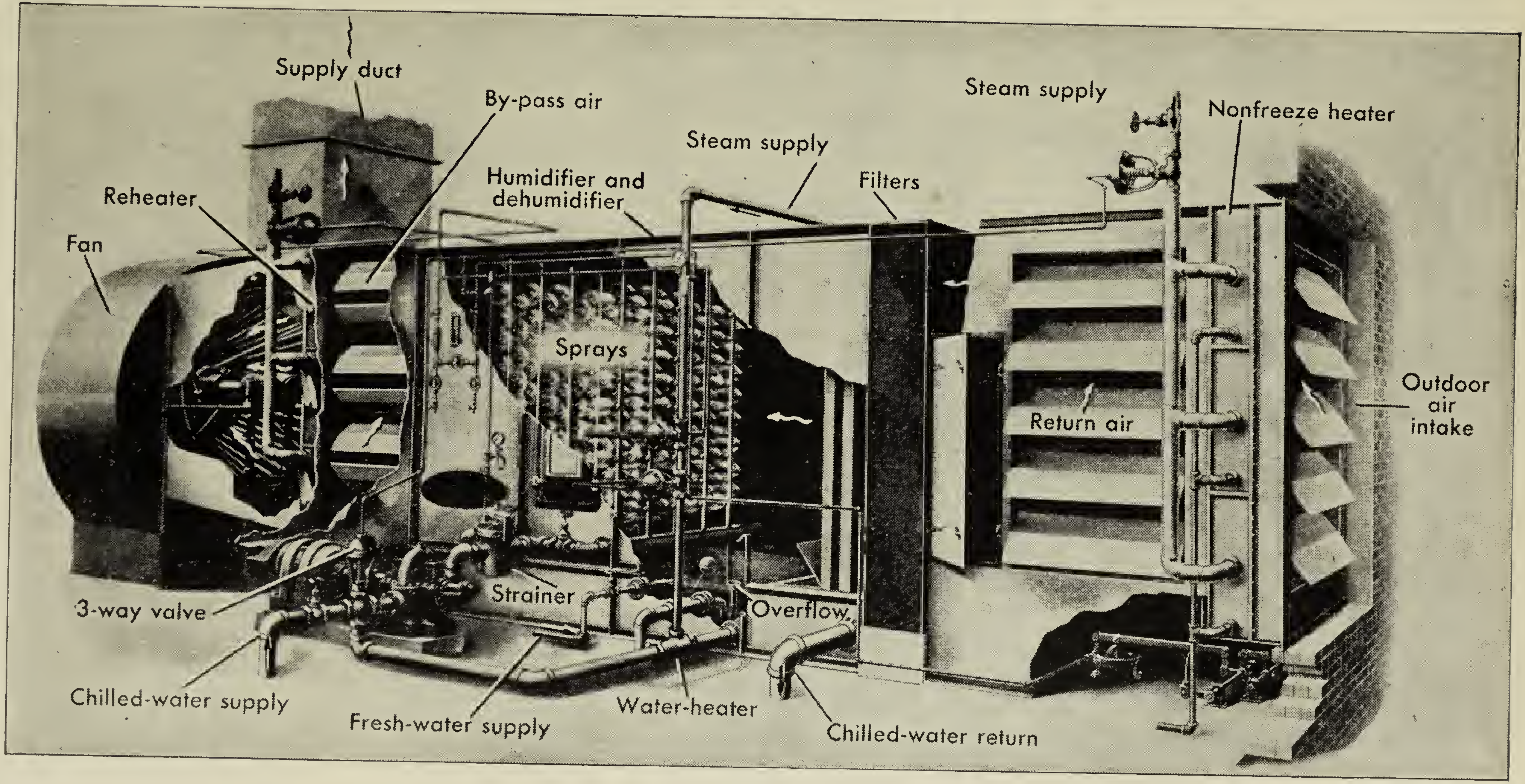
[1] W. H. Carrier, "Air Conditioning in Relation to Industrial Hygiene," *Industrial Medicine*, September, 1938.


Supply duct
By-pass air
Steam supply
Steam supply
Nonfreeze heater
Humidifier and dehumidifier
Filters
Reheater
Fan
Sprays
Outdoor air intake
Return air
3-way valve
Strainer
Overflow
Chilled-water supply
Fresh-water supply
Water-heater
Chilled-water return

Carrier Corporation

An air-conditioning machine

more slowly; but within an hour some relief was afforded, and at the end of fifteen hours their symptoms were comparatively mild. After thirty-six hours scarcely any symptoms were in evidence.

Questions for Study

1. In what ways does modern home life differ from the everyday life of ancient peoples with respect to the utilization of energy?
2. How has the development of the steam engine contributed to the advancement of civilization?
3. Why does the water in an automobile engine running at a rather high temperature often begin to boil when the car is stopped?
4. What is meant by the efficiency of a machine? Why is the efficiency of a machine important in industrial life?
5. It has been said that in the past few years the world has become progressively smaller. What has the use of heat had to do with this result?
6. In many of the modern streamline trains an internal-combustion engine is used to run a generator which produces the electricity that drives the locomotive. What is the advantage of this roundabout way of applying the power to the train?
7. Why is it possible to purchase today, for a comparatively small sum, an automobile which is vastly superior to earlier automobiles that cost a great deal more?
8. What scientific principles are employed in the modern home refrigerator?
9. In what ways has increased knowledge of refrigeration changed living conditions in the home?
10. How has the development of heating and air-conditioning equipment modified everyday living conditions?
11. How is the use of frosted foods modifying modern life?
12. How many ways can you cite in which man's increased knowledge and use of heat have added to the comforts and enjoyment of living?

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CHAPTER NINETEEN

Magnetism and Electricity Have Changed the Life of Man

Knowledge of Magnetism Has Developed through a Long Period of Time. No one knows when or where magnetism was first discovered by the ancients. There are different traditions concerning it. It seems probable, however, that the term is derived from *Magnesia*, the name of a province of Thessaly, in which were found large quantities of magnetic iron ore. Socrates relates, "that stone not only attracts iron rings, but also imparts to them a similar power of attracting other rings; and sometimes you may see a number of pieces of iron and rings suspended from one another so as to form quite a long chain; and all of them derive their power of suspension from the original stone."[1]

A lodestone

It seems probable that the first practical use made of magnetism was in connection with the compass. But just why the compass needle swings to a north-and-south position remained for William Gilbert (1540–1603) to work out. Some thought it was a response to a directional influence centering at some celestial pole; others fantastically attributed it to the rotation of an iron mass in the tail of one of the constellations. Gilbert was an English doctor who "practiced as a physician with great success and applause," but whose avocation was experimental magnetism and electricity. For that period he possessed a remarkably strict scientific attitude and had no patience whatever with the schoolmen of his day, who depended almost entirely upon books for their information. He said that true scientists, whom he styled "modern philosophers," must cease to depend upon books as sources of information and must study nature if they wish to avoid error; for "men of acute intelligence, without actual knowledge of facts, and in the absence of experiment easily slip and err"—an admonition to which all scientists of the twentieth century heartily subscribe.

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[1] *Dialogues* of Plato.

His extensive investigations in magnetism were made possible through a pension granted by Queen Elizabeth, to whom he was physician. In the course of his studies it occurred to Gilbert that the reason why compasses behave as they do is that the earth itself is a giant magnet. Faithful to his convictions as to the virtue of experiments in arriving at truth, he procured a lodestone and fashioned it into a sphere like the earth. Now, bringing a pivoted, magnetized needle near this little lodestone globe, he was delighted to find that it behaved exactly as compasses do when brought into proper relations with the earth. Because of this similarity between his globe and the earth, he called the former the *Terrella*, or "little earth."

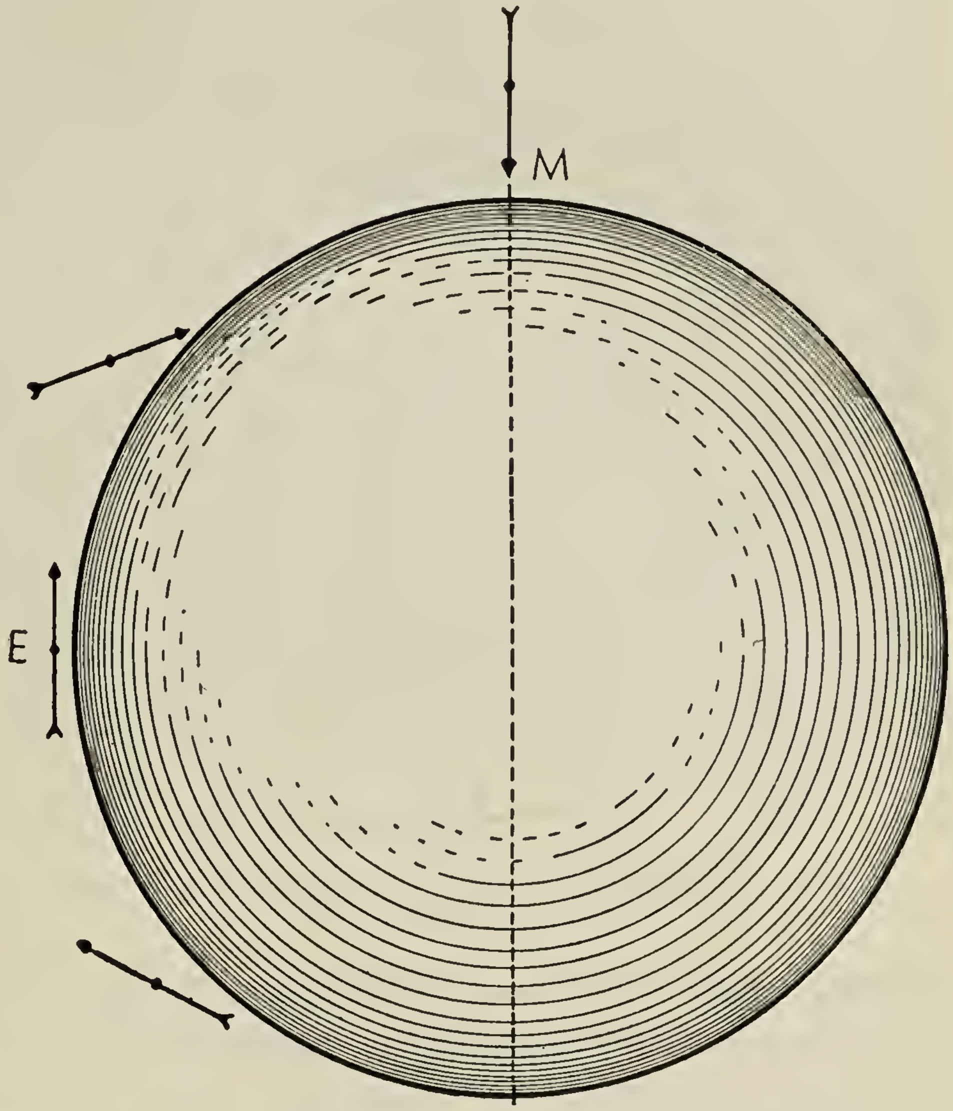
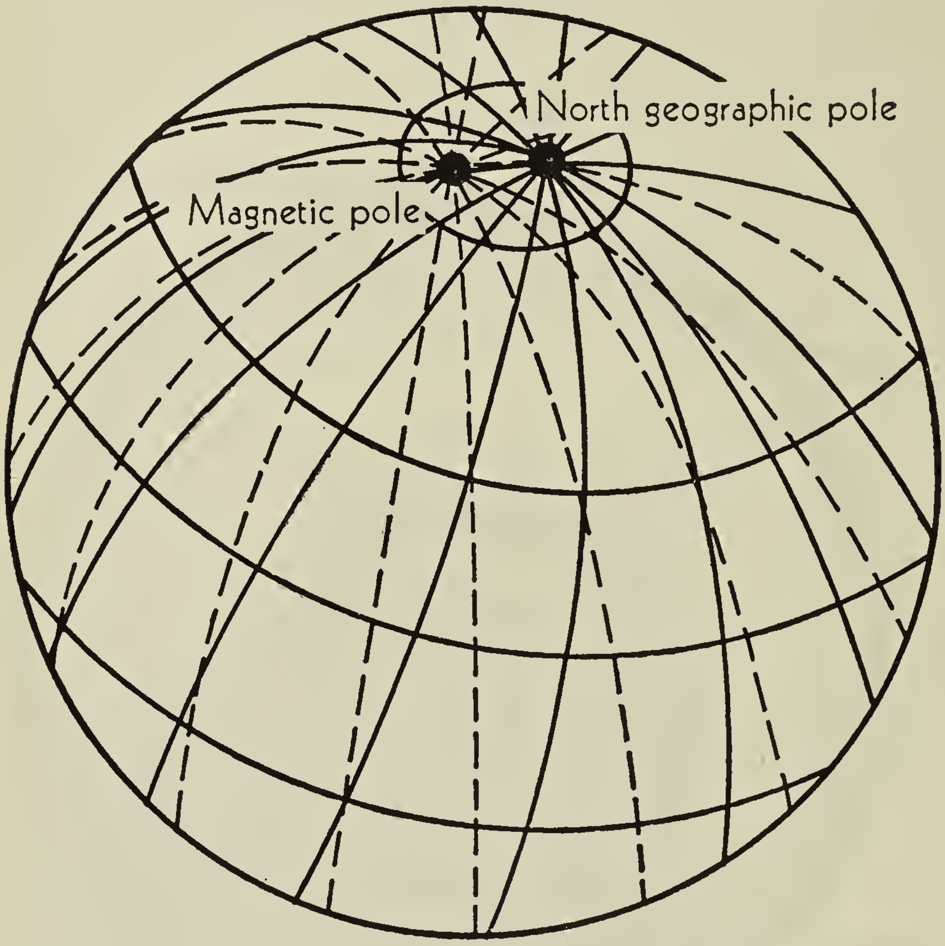


Diagram of Gilbert's Terrella

M, magnetic pole; *E*, equator

By the use of the Terrella, Gilbert also found out that what we call the north magnetic pole of the earth corresponds, as a matter of fact, to the S, or south-seeking, pole of a magnet. Strangely enough also the magnetic poles of the earth do not coincide with the geographic poles, neither are they fixed exactly in point of time. The magnetic poles are several hundred miles from the geographic poles and shift about slightly under such influences as the changing seasons, volcanic eruptions, sunspot cycles, and doubtless other natural phenomena.

The Particles of a Magnet Are Believed to Be Polarized. Certain substances respond to the influence of magnets and become magnetized themselves. The easiest substance to magnetize is soft, malleable iron; but a few others, such as nickel and cobalt, respond to the same influence, although to a lesser degree. If a bar magnet be held under a sheet of paper upon which iron filings are sprinkled, the filings immediately arrange themselves in definite, more or less elliptical lines. The positions assumed by the filings indicate so-called magnetic lines of force. The region of force indicated by the filings is a magnetic field. It is evident that although the filings on the paper show but a plane section of the field, all the lines that must exist, both indicated and invisible, taken together would approximate a sphere.



The relative positions of the magnetic and geographic poles of the earth

But why are magnets accompanied by these magnetic lines of force? There is a great deal of evidence to support the theory that magnetism may be the result of a definite molecular or, in some cases, atomic arrangement. If one takes an unmagnetized steel bar and repeatedly strokes it lengthwise in the same direction with one end of a strong magnet, the bar itself will gradually be converted into a permanent magnet. One end of the bar will be an S (south) magnetic pole, and the other an N (north) magnetic pole. Now if one breaks the bar in two, each half becomes a magnet with its appropriate poles. If each half be broken in the same way, four magnets may be formed. There seems to be scarcely any limit to the number of magnets which may be produced from the bar in this way. It is believed that the division might proceed down to the very molecules[1] themselves, and that each molecule then might be considered to be an infinitesimally small permanent magnet with its N and S poles.

Now the only reason why an ordinary unmagnetized steel bar, such as we started with in the first place, did not exhibit magnetic properties at the outset

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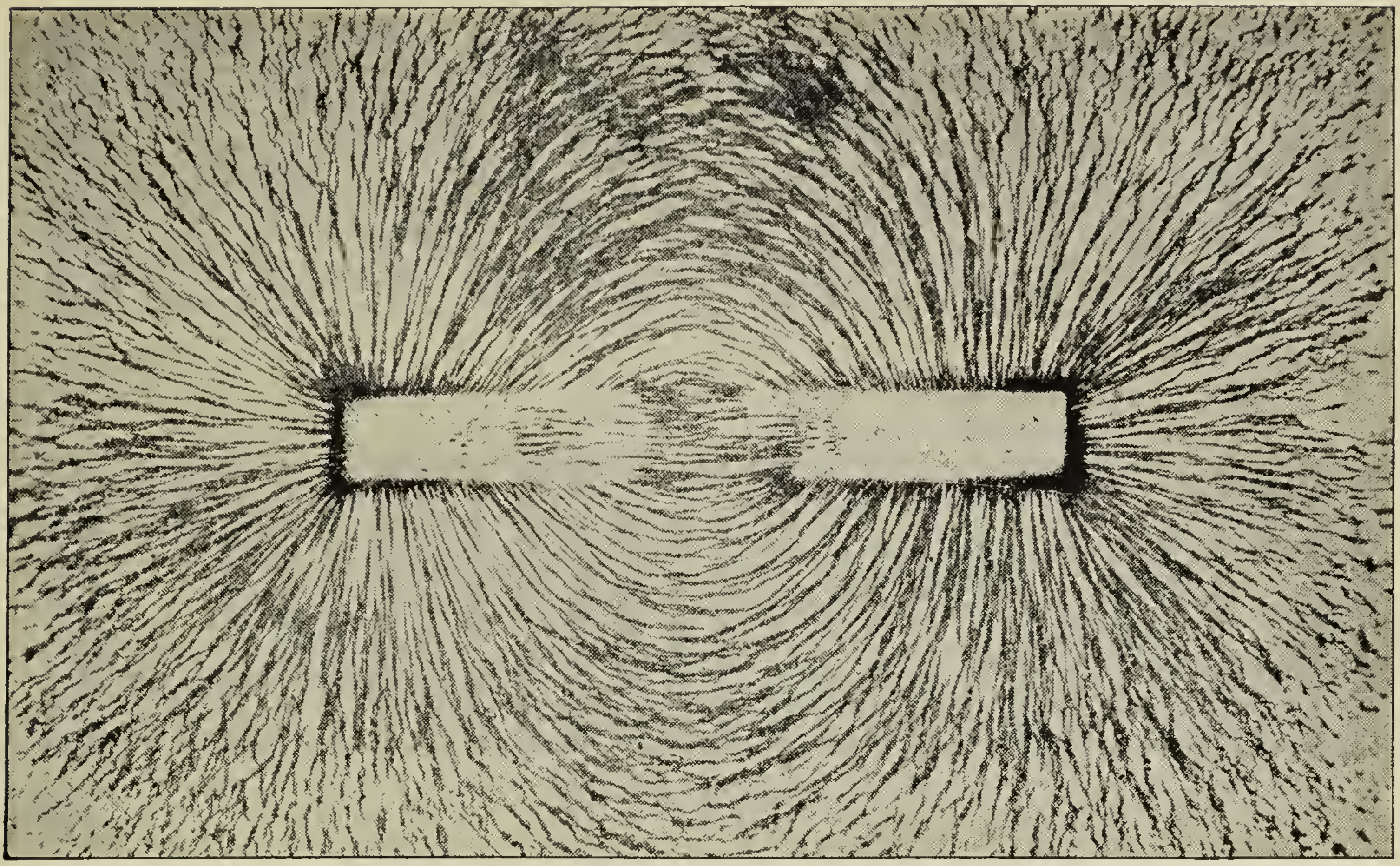
[1] Since iron is monatomic, the molecule in this case is believed to be the same as the atom.

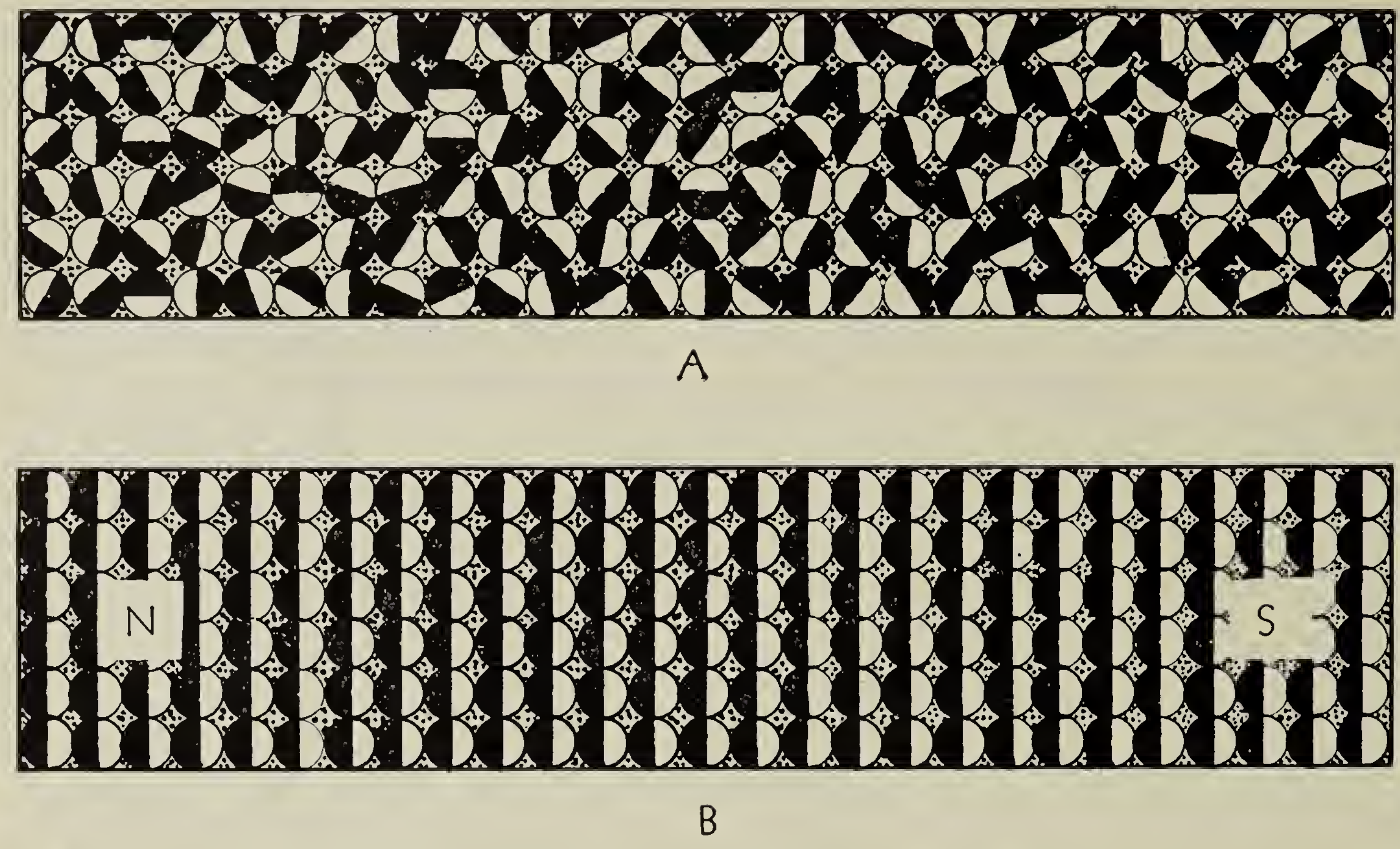


Lines of force about a magnet

Iron filings are used to indicate the lines of force in the magnetic field about a bar magnet

was that its molecules were arranged throughout the whole bar in a higgledy-piggledy, or unoriented, fashion. Consequently the lines of magnetic force exerted by each molecule were all mixed up with reference to one another. But when the molecules were agitated by the influence of a moving magnet, they were induced to take up a definite polarized position, just as disorganized soldiers are brought into line by the voice of their commanding officer. In this condition perhaps all the molecular N poles were pointed in one direction and the S poles in the opposite direction. By this molecular orientation all the tiny, feeble lines of magnetic force about each particle were brought into coincidence and made to reinforce one another. It was the cumulative effect of these millions of miniature magnets combined that gave the whole bar its magnetic power.

Further evidence that the magnetization of a steel bar depends upon the proper orientation of its particles is added by the fact that a permanent steel magnet may be destroyed by heating it to a high temperature or by vigorous, prolonged pounding. It is probable that the increased molecular action induced in either of these ways throws the molecules out of alignment and mixes them up, just as the heavy ball in a bowling alley, when a center shot is made, crashes into the carefully oriented pins and knocks them from their orderly position into a confused pile.



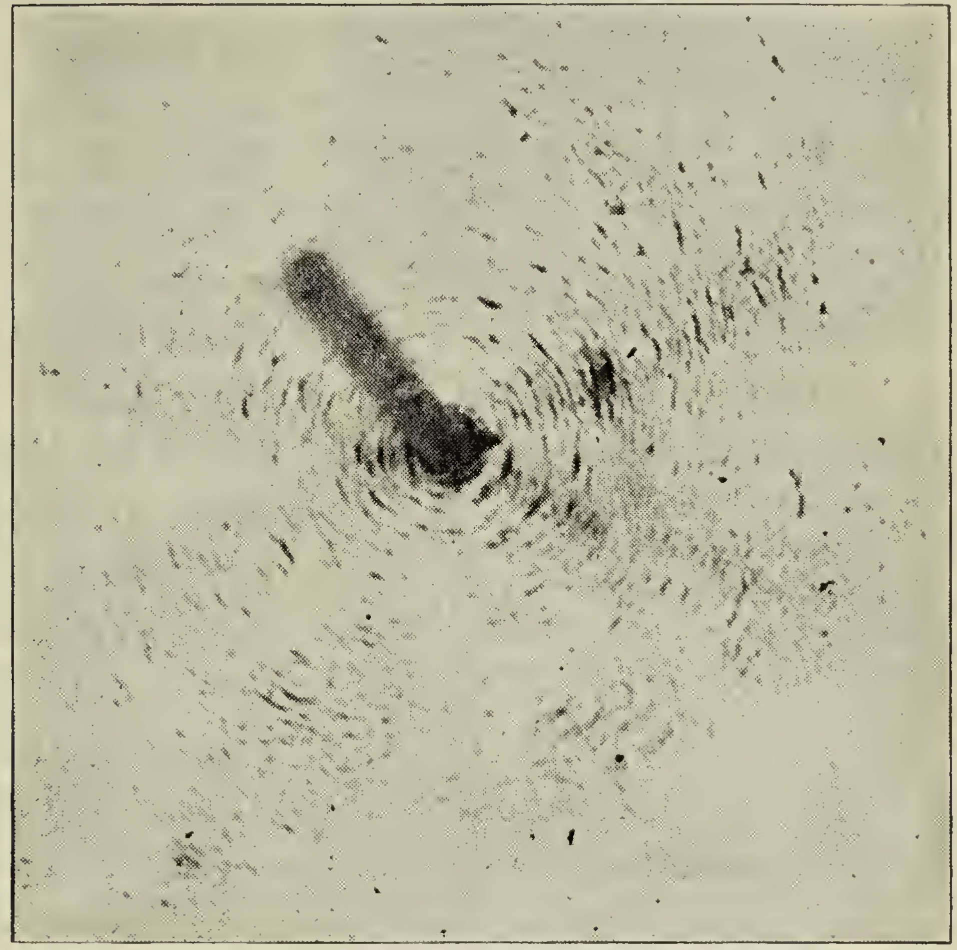
The arrangement of the particles in an iron bar

A, before magnetization; *B*, after magnetization

This theory of magnetization is further substantiated by the magnetic effects produced in shipbuilding and other steel-manufacturing processes. We are told that a strike occurred among the steel-riveters during the construction of a certain cargo steamer in England. While the labor difficulties were being adjusted, work on other parts of the ship proceeded. The plating was all completed, and the bulkheads and decks were built in. At this juncture careful notation of the amount of the boat's magnetism was made. The labor dispute being settled, the riveting was then resumed, with its continous pounding impacts. The particles of the steel plates, in particular those plates in a north-and-south position and parallel to the earth's magnetic lines of force, constantly agitated in this way were gradually maneuvered into the polarized positions by the gentle but continuous pull of the earth's magnetic lines of force. By the time the riveters had hammered in 40 per cent of the rivets, the ship's magnetism had risen over 30 per cent, and as the riveting continued, magnetization went on, constantly increasing to the end.

Lodestones, which, of all the iron ores, have the highest percentage of iron, are likely to have their molecules polarized by the continual action of the earth's magnetic lines of force. It may be, too, that the jarring effect of earthquakes, thunder, and volcanic eruptions, and the heating effects of the sun, acting in conjunction with the natural kinetic movements within the stone, may be contributing factors to the magnetized condition.

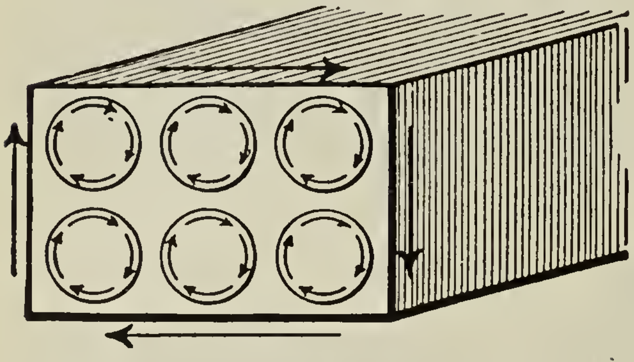
The Magnetic Property of an Iron Bar Is Due to Co-ordinated Electron Movement. To support the molecular-arrangement theory of magnets we have much evidence. This theory was suggested by certain observations made on the effects of an electric current passing over a wire. For example, if a sheet of paper be pierced at right angles with a vertical copper wire carrying a strong direct current of electricity, and fine iron filings be sprinkled on the upper surface of the paper around the wire, the filings will arrange themselves in concentric rings about the wire similar to their action when a permanent magnet is used. This shows that a wire carrying an electric current is always surrounded by a magnetic field. An electric current, as we are to see later, is believed to be nothing more nor less than a stream of electrons passing over a suitable conductor, such as a wire. Carrying our deductions a step farther, we are led to infer that probably all magnetic fields of force are the complementary accompaniments of traveling streams of electrons, and that the lines of force take a position at right angles to the direction of the current. Let us now see how this can be explained theoretically.



Magnetic field surrounding a current-bearing wire

Iron filings are used to demonstrate the magnetic field surrounding a current-bearing wire

In a bar magnet we have found that the molecules are conceived to be all lined up, like needles in a pack, with their north poles pointing one way and their south poles the other. This brings the atoms into such a position that the movement of the electrons about their atomic nuclei tend to proceed in one direction, like soldiers marching in ranks. These myriads of electrons, then, all moving in unison as to direction produce the magnetic lines of force at right angles to their course. As long as the molecules remain lined up in polarized formation, just so long will the bar remain a magnet; but let the molecules be again stirred up into a topsy-turvy condition, and the magnetic field is destroyed. The particles in a steel bar appear to be moved into the polarized position with difficulty. It takes prolonged stroking with a strong magnet to do it. But, once they are oriented, they seem to offer an equal resistance to breaking ranks and being thrown into disorder again. For this reason a hard steel bar, when once magnetized, retains this property for years; indeed, almost indefinitely. A soft-iron bar, on the other hand, is much like the student who learns his lessons easily but soon forgets them. Its molecules apparently offer almost no resistance at all to being polarized. They fall into step at the least stimulation by a magnetic field. But almost the instant the magnetic stimulus is removed, the molecules fall into disorder and confusion again, and the magnetic properties of the bar are thereby destroyed. This nonresistant character of soft-iron molecules to being either polarized or depolarized, however, is of inestimable value to the whole field of industrial electricity. In fact, the electrical age, in which we now live and which has done so much to make life interesting and attractive, would be quite impossible were it not for this "easygoing," nonresistant characteristic of malleable iron.



End of a Bar Magnet

The small circles represent some of the atoms of which the bar is composed. The arrows in the circles indicate the direction in which the electrons revolve. The combined motion of the electrons is equivalent to an electric current flowing around the bar

It will be shown (p. 335) that electric currents are always accompanied by a surrounding magnetic field. The converse is also true. Shifting magnetic lines of force always stir up the electrons and induce a corresponding electric current on any suitable body that they strike. So we see that magnetism and current electricity, like an object and its shadow, are inseparable. Produce one, and the other is there also; destroy one, and the other disappears at the same instant. It is no accident that the words *electricity* and *magnetism* came to be fused into the one compound word *electromagnetic.* They cannot be separated either in our thinking or in practice.

Electricity May Exist in the Static Condition. So far as we know, the first man who ever experimented with electricity was Thales, who lived about 600 B.C. and who was one of the "seven wise men" of early Greece. He discovered that when a piece of amber was rubbed with a woolen cloth, it would pick up light objects, such as bits of paper, pith, or straw; but centuries were to pass before electricity was to be looked upon as anything but a peculiar phenomenon—a thing to be played with.

At the beginning of the seventeenth century Dr. William Gilbert, the man who made the Terrella, repeated Thales' experiments with the amber and a woolen cloth. He also found that glass or sealing wax could be used instead of the amber. Greatly interested, he tried to find out just what the cause of this attraction was. He, in those early days, was unable, of course, to solve such a subtle mystery. He did make a permanent contribution, however, by naming electricity. Remembering that the Greeks had first noted this phenomenon in connection with amber, he called this new form of energy "electric" after the Greek *elektron*, meaning "amber." From this came our word *electricity*.

Anyone can repeat Gilbert's experiments by taking a hard-rubber comb and rubbing it briskly on the sleeve of his woolen coat and then applying it to tiny bits of thin paper. The particles of paper literally jump up to meet the comb. And if the day is cold and dry and the comb is well charged, the bits of paper will cling together in chainlike groups. Gradually the comb seems to lose its attraction for the paper, and in a few seconds the bits cease to respond to it at all. If a glass rod is rubbed with a silk cloth, the rod also will pick up certain objects, although the charge produced on it will be of an opposite character.

Why objects rubbed in these ways became electrified and could actually pick up things remained a profound mystery for several centuries. Two or three theories were advanced; among them was one by the wise, curious-minded Benjamin Franklin. Getting his idea from the sparking effect produced by electrified bodies, he advanced the theory that electricity is a sort of imponderable fiery fluid which could either pass to or depart from material bodies with ease. Whenever an object had an excess of electricity, it manifested what he called "positive," or "plus," properties; if, for any reason, the supply became reduced below the normal, the object became "negative," or "minus," in character; when it had an intermediate amount of electricity, then it was neutral. Although Franklin's theories, both as to the nature of electricity and as to electric charges, were altogether erroneous, we are indebted to him for proposing the words *positive* and *negative*, *plus* and *minus*, all of which seemed appropriate and have been generally adopted as current electrical terms.

The true nature of electricity remained a baffling puzzle until more than a hundred years after Franklin's death. It was not until the new theory of matter threw a flood of light on this deep mystery that physicists began to have any idea of why bodies have positive or negative charges, or, lacking either of these, are electrically neutral.

All of which illustrates the verity of the scientific attitude that "truth itself does not change but man's conception of truth often does change." Electricity as a form of energy is not one whit different from what it was when the inquisitive-minded Franklin and his friends were experimenting with it or, for that matter, when Thales, six hundred years before Christ, was electrifying amber by rubbing it with a woolen cloth. But note how man's conception of electricity has changed. New discoveries as to the structure of the atom have made Franklin's ideas of a "fiery element" appear entirely untenable. A similar change has taken place in man's conception of the cause of disease, the nature of comets, the forces behind weather changes, or the factors that cause children to resemble their parents. One must not assume, of course, that our present theories are fixed and final. They too may change.

Static Charges Are Produced by a Shift of Electrons. The light dawned on this perplexing mystery as soon as the electrical character of matter itself was discovered. The atoms of all bodies, as we have found, are believed to consist of positively charged nuclei with their associated negative electrons. When there are just enough electrons to balance the positive charges of the nuclei, the body is electrically inactive, or, as we say, neutral; but if something happens to an object that results in the removal of some of its electrons, this leaves a number of unbalanced positive atomic nuclei, and the body is positively charged. This is exactly what happens when a glass rod is rubbed with silk cloth. Now, since the silk fibers pull electrons off the glass rod, it is obvious that the electrons accumulate simultaneously on the cloth,—that is, the cloth becomes negatively charged,—and the glass rod in turn takes on a corresponding charge of positive electricity. When one rubs a rubber comb or rod on the sleeve of his woolen coat to electrify it, the rubber steals electrons, thereby becoming negatively charged itself and leaving a corresponding positive charge on the coat sleeve. The reason why the rubber, when in this state, picks up bits of paper is that positive charges are induced on the portions of the bits of paper next to the rubber. Since the electrons have been repelled to the portion of the bits of paper farther from the rubber, these negatively charged margins in turn act on still other bits of paper to electrify them, just as the rubber charged the first series of bits of paper to start with. In this way the bits of paper may be caused to cling together in a series, or chain.

Why the bits of paper in a few minutes refused to respond to the rubber can easily be explained also. The electrons gradually dissipated off the rubber. Some probably drifted out into the surrounding air, some passed to the bits of paper themselves, and still others may have leaped across to the hand holding the rubber. When the rubber became neutralized, it lost its power to induce charges on the tiny paper particles.

Lightning Results from Static Charges in the Air. Everyone has been startled by the sharp, earsplitting electric discharges that occur during a severe thunderstorm. On the basis of laboratory experiments and investigations of the electric charges carried by falling raindrops it seems probable that these static charges are the product of forces acting within the storm.

One investigator, by directing a tiny stream of falling water against a vertical jet of air, blew the water upward in a fine spray. By this division of the water into minute droplets it was found that the ordinarily balanced electric charges residing on the neutral water particles were separated into charges of positive and negative electricity. The positive charges tended to remain on the water droplets, while the negative charges tended to electrify the more minute water particles and move upward with them. It seems probable that in all thunderstorms there are upward currents of air which tend to break up the drops of water into smaller ones and thus electrify them. The rolling, tumbling thunderheads that often form on hot afternoons furnish visible evidence of this. At Frankfort, Michigan, which has become a prominent center of glider-plane activity, some remarkable discoveries have been made with reference to upward currents of air. The following corroborated report was made:

> There are winds called "thermals" which blow straight up, usually through the middle of a fleecy white cloud. Bob Stanley, an American ace, last summer hooked on to a "thermal" which rose 17,264 feet, sometimes at the rate of 3000 feet a minute.[1]

Many of the electrically neutral drops of water condensed in a cloud are boosted upward by these vertically surging drafts of air. In this way the drops are believed to be split up in such a manner that the fine outer fragments, bearing a negative charge, are torn away and are carried upward into the top of the cloud. The larger central parts of the drops, carrying the corresponding positive charge, remain in the cloud base or drop to the earth. In this way the positively charged water particles tend to form the bottom of the cloud, while the negatively charged air and finer water particles tend to form the top of the cloud. Sometimes side currents of air may carry the top of a cloud on past the lower portion of it. In this way two separate clouds will be formed, one negatively charged and the other positively charged.

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[1] "Soaring on a Shoe-string," *Rotarian*, Vol. 55, pp. 16–18. (1939)

Charged "clouds" may develop from the rubbing against one another of dust particles, which separates the positive and negative electricity. Albert B. Regan, of the Indian Field Service, reports that in Arizona on a clear day he observed a strong whirlwind pass up a steep, narrow canyon. Just before entering the canyon it had passed over an ancient lava bed and had picked up a cloud of dust. As it entered the canyon, "in a moment there were chain lightning and ripping thunder on every side, while at the same time the twister uprooted trees and tore large-sized boulders from their places on the canyon walls."[1]

Since the electric charge resides on the outer surface of an object, the positive charge at the bottom of a cloud, or electrical potential, as the physicist expresses it, would tend to increase as the total surface area of the drops of water was reduced by further condensation into larger drops.

As this condensation proceeds, the total charge on all the drops mounts up with incredible speed. In this way the cloud may develop a very high positive charge, or positive electrical potential, in its lower portion.

Now a heavy positive charge on the lower part of an overhanging cloud can act as a powerful attractive force to bring electrons to the portion of ground beneath that cloud. The result is that a commensurate charge of negative electricity is induced on the earth at that point. Sometimes the *induced* charge is formed on a neighboring cloud, or on both the ground and neighboring clouds.

The two charges are kept apart only by the tremendous resistance interposed by the air, which, under ordinary conditions, is a nonconductor. Ultimately the potential difference between the two oppositely charged regions may grow so high that it will overcome the atmospheric resistance. Then an electric discharge, or, as we say, a flash of lightning, occurs. Following the line of least resistance it darts through the air in zigzag fashion, forming a brilliant streak of light as it goes.

It was formerly believed that the fiery streak marking the pathway of discharge was produced by the particles of dust and molecules of air which were heated to incandescence. More recent investigation seems to discredit that view. The flash seems rather to be produced by the readjusting and reforming parts of the disrupted atoms. Recent views as to the origin of light waves seem to support this theory, as we shall see later.

The thunder is believed to be caused largely, if not entirely, by a sudden increase of pressure due to the heating of the air and the ionization of its atoms. It has been estimated that in the path of a bolt a mile long and a foot in diameter the air would be heated to a temperature of over 1100° F. The sudden expansion resulting from this rapid increase in temperature would "bang" the air particles against one another with great force and would set up intense air waves, resulting in sharp claps of thunder. The reverberating and prolonged "rolling thunder" is thought to be caused by echoes and re-echoes from surrounding clouds and other objects, such as mountains, hills, and forests.

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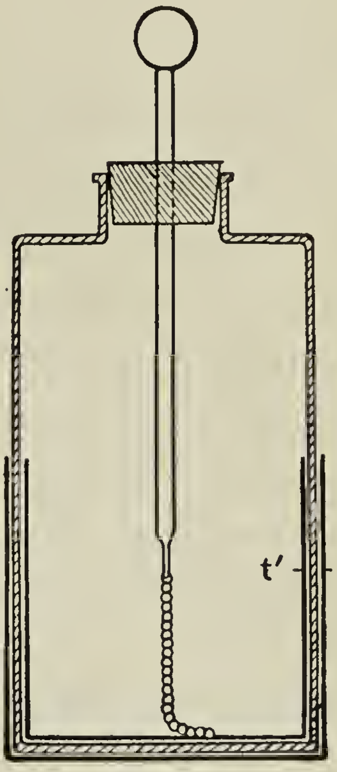
[1] "Sand-Storm Electricity," *Science*, Vol. 71, p. 506. (1930)

The splitting, tearing effect of lightning bolts when they strike an object, such as a tree or telephone pole, is considered to be due to a sort of explosive effect. All such objects contain some water. The resistance offered to the passage of the charge results in such a sudden high temperature that the water is instantaneously converted into steam. Being confined, it explodes with disastrous results. It is also possible that some of the solid elements of the wood are suddenly converted into a gas which further augments the force of the explosion.



Leyden jar

t and t′, the foil covering the jar

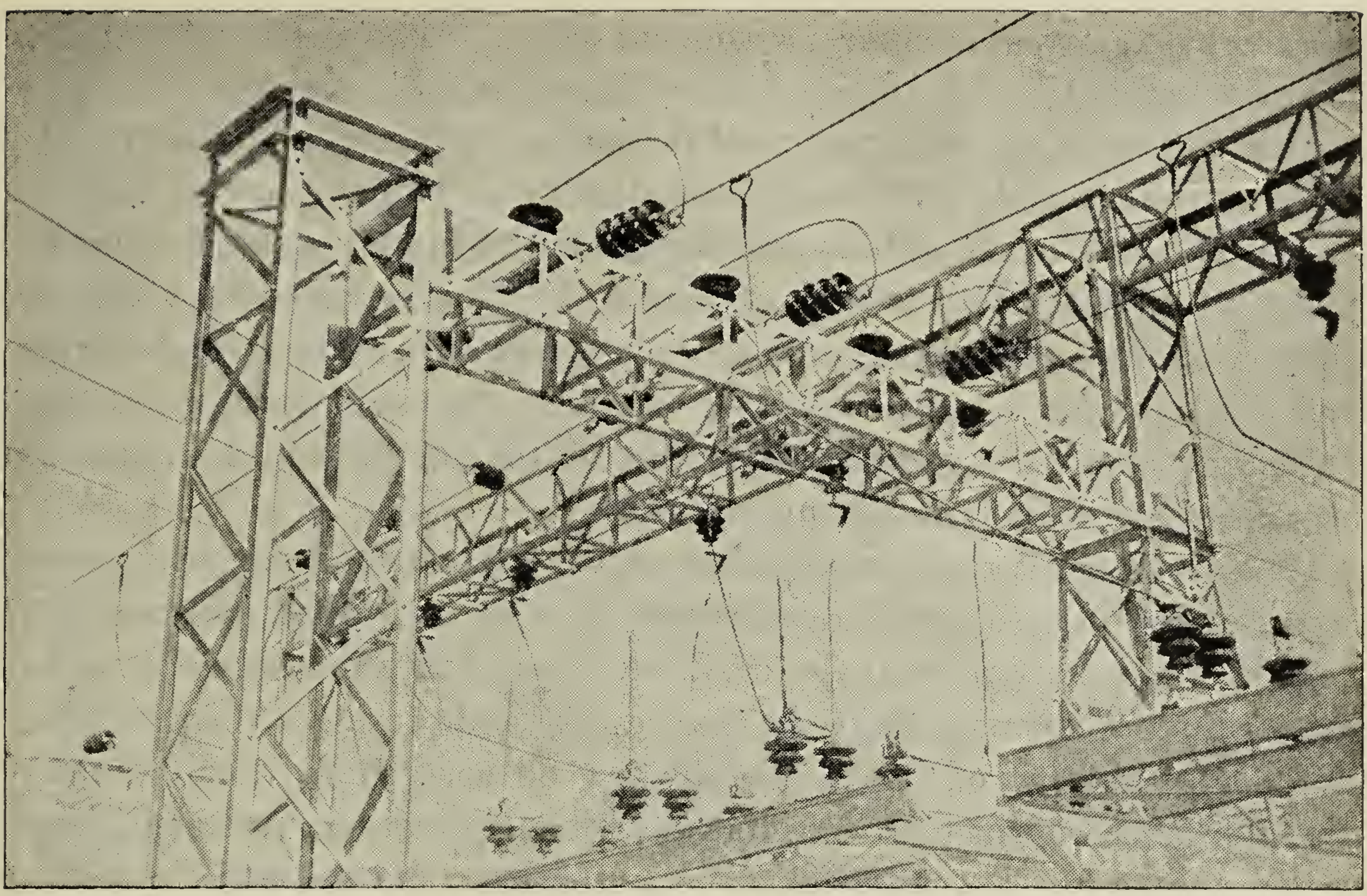
We have all attempted to pick up a telephone receiver, or turn on a radiator valve, or touch another person on a cold, dry day and have received "an electric shock." This discharge was only a miniature streak of "lightning" between our bodies and the other object. As we previously sat at our desk rubbing our arm over the paper as we wrote, or stroked the nap on the rug with our feet as we walked across the room, we rubbed electrons off in each case and produced a charge on our bodies. Then as we approached the other object, an opposite charge was suddenly induced on it, and a spark occurred as soon as the air gap between the two became too narrow to hold the charges apart.

The Leyden jar is but an electric condenser capable of taking on a very high potential, because of which it too may be discharged, producing a spark. The tin foil of the jar may be charged by a static electric machine. Since the foil on the inside is connected with the machine and the foil on the outside is connected with the earth, the foils have strong opposite charges simultaneously induced upon them. Great care must be exercised in handling Leyden jars when charged, to prevent the discharge from the inner to the outer foil from taking place through the body. Pieter van Musschenbroek, a professor at the University of Leyden, was trying one day in 1746 to electrify some water in a bottle. At first he did not understand the principle of the

Leyden jar discharge. A friend who was assisting him accidentally got a shock, "as by a lightning stroke." His curiosity aroused, Van Musschenbroek himself tried it. He got such a shock, as he expressed it to Réaumur in a letter, "that he would not take another—for the kingdom of France."

Some Substances Are Conductors; Others Are Insulators. It was learned by the early investigators of electricity that there is a great difference in the behavior of a charge when placed upon different substances. Stephen Gray, an irascible old schoolmaster of the Charterhouse School, was experimenting with electricity during the first part of the seventeenth century. He noticed that electricity apparently passed from a glass rod, which he had electrified by rubbing with a silk cloth, to an ivory ball attached to the end of the rod, and that the ball itself became electrified. He next tried a fishing rod to which he attached an ivory ball, and found that the "vertue" moved from the rod to the ball as before. Greatly interested, he mentioned this peculiarity to a friend, and after discussing the matter they decided to try the new discovery out on a grand scale. They suspended a wire by nonconducting silk threads from the roof of a long gallery and ran it back and forth until the line was more than three hundred feet long. To their great delight, when a well-stroked amber rod was brought into contact with one end of the wire, the "vertue" passed the whole length of the wire and manifested itself at the opposite end. Although before this a German had passed "vertue" over a short linen thread, this was without doubt the world's first metal transmission line. The experimenting was continued, and then occurred one of those rare accidents which led to another very important discovery. On one occasion, according to the story, one of the silken threads broke under the weight of the wire, and in their eagerness to proceed, since there was no other silk thread at hand, Gray and his friend used a piece of wire as a support instead. To their great surprise the electricity would not move along the wire as before. "No matter how much they rubbed the amber at one end, the 'vertue' never reached the ball at the other." What could have stopped it? Then it occurred to them that it might be the metal support which was diverting the current. Removing the wire and again substituting silk, they found that the experiment worked as before. Although they lengthened the line to over six hundred and fifty feet, the "vertue" passed without interruption.

Here, in that remote day, was the clear discovery that some substances will conduct electricity readily, while others will not. The reason for it, to be sure, was unknown, so the secret as to the cause of this difference in conductivity had to wait for the illumination of more scientific knowledge. This was afforded by the recent discoveries as to the nature of matter and the con-



Porcelain insulators on a high-tension line

clusion that an electric current is a stream of electrons moving along some conducting medium, such as a plate or a wire.

Substances that conduct a current readily are called *conductors.* Those that will not conduct a current are known as *nonconductors.* Although these two classes are supposed to stand in marked contrast to each other, there is really no sharp line of distinction between them. There is no conductor which at ordinary temperatures does not offer some resistance to a flow of electrons, just as there is no nonconductor that will not let some electrons pass.

In practical electrical work effective nonconductors are called *insulators.* Glazed porcelain, glass, rubber, and Bakelite are examples of good insulators. Unglazed porcelain may be used when protected from rainfall and other water. Otherwise, since it is highly porous, it would absorb water and become a conductor. Even the glazed-porcelain or glass suspension insulators are composed of a series of bell-like parts, so that if the weather-exposed surface becomes covered with a water film during rainy weather, the dry, under portion of the bell-like parts in series will still offer the necessary resistance. The electric cord used in our homes, to take another common example, is covered with a coating of rubber for insulation. The cloth-fiber web plaited around the rubber coating which surrounds the wire is to prevent the rubber from being worn through at points of friction. One of the best conductors is silver, closely followed by copper, aluminum, carbon, and others. Almost all the metals are good conductors.

This difference between the current-bearing properties of different materials is of inestimable value in the industrial arts. To have an electrical industry it is necessary not only to generate electricity but to be able to conduct it, like water in a pipe, wherever it is wanted. This explains why electrical transmission lines are made of copper or aluminum—they would doubtless be made of silver were it not so expensive—and why the use of porcelain or glass hangers prevents the current from jumping off the line to form short circuits and thus endangering both life and property.

Then just what is the difference between conductors and nonconductors? Physicists now believe it to be a matter of the ease with which electrons can be made to pass from atom to atom. Substances in which the electrons can be made to jump from one atom to the next readily, and because of this condition have a large number of free electrons, are good conductors. On the other hand, substances in which the electrons are not easily induced to change places are nonconductors. The more difficult it is to bring about the transfer of electrons, the better insulator the substance is.

Lightning Rods May Reduce the Electrical Potential between Earth and Cloud. Lightning rods are often employed to prevent loss from lightning and subsequent fire. Scientists, however, have very different ideas as to wherein the real efficiency of lightning rods lies. Some scientists believe the rods are to conduct to the ground a bolt that otherwise might strike the building upon which they are erected. If the rods are made of a good conducting metal, such as copper, are of sufficient size, and are properly grounded in the damp earth, they doubtless are highly effective in preventing loss from this source. The Bureau of Standards maintains that this is their only value.

> The sole purpose of lightning rods or grounded metal roofs is to protect a building in case a stroke occurs, there being no evidence or good reason for believing that any form of protection can prevent a stroke.[1]

Other scientists readily admit this value but at the same time insist that protection is also achieved in another way. It is a well-known fact that an electric charge carried by a body resides on its surface rather than throughout its mass. If the body is hollow, it is the outer surface that is electrified rather than the inner. This condition arises from the fact that parts of the same charge tend to repel each other and are thus driven as far apart as possible. If the surface is a uniform sphere, the charge is evenly distributed over the outside. If, however, the surface is an uneven one, having sharp curves, angles, corners, or points, the quantity of electricity per unit of area is greatest where the sharpest angles are found. As a result, particles of air coming in contact with the lightning-rod point are quickly charged and repelled. The place of these being taken by other particles, which in turn are charged and repelled, the result is a sort of "electrical draft," which tends to reduce the static charge and in this way prevent the potential from becoming so high as to lead to a discharge.

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[1] Bureau of Standards, *Code for Protection against Lightning*, Parts I, II, and III, p. 9. (1933)

Dr. J. B. Whitehead of Johns Hopkins University readily admits the conducting value of lightning rods but maintains that their value also arises from their charge-dissipating effect. In support of his contention he cites a group of historic trees, sixty-one in all. Sixteen of these had been struck one or more times by lightning. To protect the group from further injury he advised the owner to install a special sort of lightning-rod protection for each tree. In fifteen years since the installation of the protection, none of the trees had been struck, although surrounding unprotected trees had suffered.[1]

That lightning rods, whether by their conducting or by their charge-dissipating effect or both, do protect buildings or other objects is shown by studies made in Iowa. In this state it is estimated that about 50 per cent of the farm buildings are equipped with rods. During the period from 1919 to 1921, 28 rodded buildings were destroyed by lightning, with a loss of $87,979. During the same years 503 unrodded buildings were destroyed, with a loss of $1,060,668. Thus the value of the rodded buildings lost was but 8.2 per cent of the value of the unrodded buildings destroyed.

There is also danger of personal injury during electrical storms. The Bureau of Standards gives the following advice for personal safety:[2]

> I. Do not go out of doors or remain out during thunderstorms unless it is necessary. Stay inside a building where it is dry, preferably away from fireplaces, stoves, and other metal objects.
>
> II. If there is any choice of shelter, choose in the following order: (1) Large metal or metal-frame buildings. (2) Dwellings or other buildings which are protected against lightning. (3) Large or small unprotected buildings.
>
> III. If remaining out of doors is unavoidable, keep away from the following: (1) Small sheds and shelters in an exposed location. (2) Isolated trees. (3) Wire fences. (4) Hilltops and wide open spaces.
>
> IV. Seek shelter in a cave, a depression in the ground, a deep valley or canyon, . . . in dense woods, or a grove of trees.

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[1] J. B. Whitehead, "Lightning Protection for Trees," *Science*, Vol. 78, pp. 506–507. (1933)

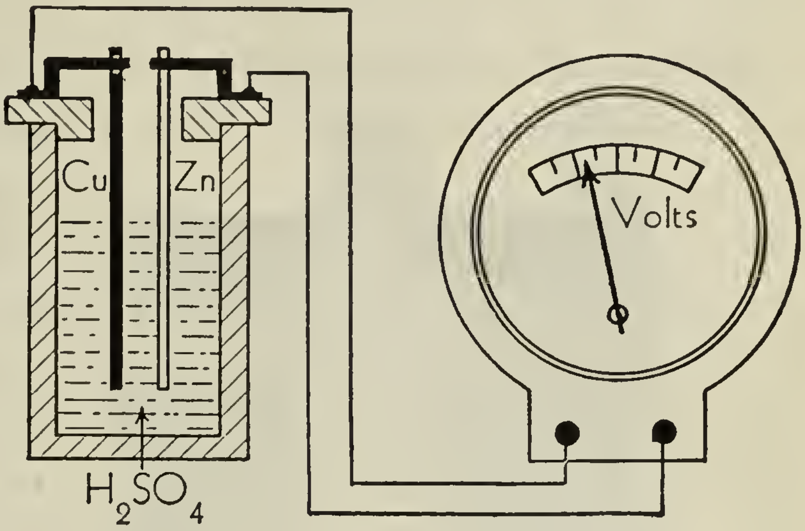
[2] "Code for Protection against Lightning," *Handbook of the Bureau of Standards*, p. 2 (slightly modified). (1933)

Electricity May Be Generated by Chemical Action. Electricity in the static form, which is produced by friction of some sort, could not play a very large rôle in the affairs of the world. Storm clouds might possess great quantities of it, but it was beyond man's reach; and to produce worth-while amounts of it down on the earth required too much "rubbing." In 1780, however, an accidental observation was made, as the story goes, which, although unimportant in itself, started a long train of experiments and discoveries that ultimately brought electricity, as a form of energy to be used, within the grasp of man. One day Galvani, an Italian professor, was dressing frogs in a room near an electric machine. An assistant happened to touch the point of a scalpel to the trunk nerve in one of the dressed frogs' legs, and immediately a pronounced twitching was observed. Curiosity was aroused, and further investigation showed the twitching to be most violent the instant a spark was produced from the machine. Here was a strange phenomenon, indeed. From this Galvani wondered what would happen if frogs' legs were brought into contact with atmospheric electricity. He promptly erected on his house a point similar to a lightning rod with a wire leading to his laboratory. He ran another wire from the laboratory outside and down into a deep well. At the approach of the first storm cloud he connected the ends of the two wires in the laboratory with a fresh frog's leg and watched for results. As soon as the storm with its electric discharges broke, the leg began to jerk and twitch most violently, and the motion was proportional to the intensity of the storm. From this Galvani was uncertain as to whether the electricity came from the leg or from the outside. To test this point he laid the frog's leg on a glass plate and, using a bent glass rod, touched the large nerve with one end of the rod and the muscle with the other. Nothing happened. But when he used a fused rod composed of copper at one end and iron or silver at the other, a violent twitching of the muscle immediately took place.

From this Galvani decided that the electricity was innate in the leg, and called it "animal electricity." We know, of course, that Galvani was wrong; for, in reality, here was the world's first chemical electric battery. The saline juices in the tissues of the frog's leg formed a passageway between the free ends of the copper and iron or silver strips, which were, in turn, in contact at the other ends. Intrinsically, Galvani's work was not very important; but we honor him today by the terms *galvanoscope* and *galvanometer*, which are seen to contain his name.

Volta, another Italian, interested by Galvani's work, became a diligent experimenter in this field. He kept on until he produced his "crown of cups," which consisted of a series of cups containing a brine or dilute acid solution, connected by combination strips of zinc and copper so arranged that the copper end of one dipped into one cup, and the zinc end into the next adjacent cup. The cups were set up so as to form a complete circular battery (later called voltaic cell), or the electric circuit could be closed by a wire connecting the end cups in the series.

Here at last we had a contrivance for producing electricity without friction: one which transformed chemical energy into a stream of electrons, or an electric current which could be sent out for indefinite distances over a wire.

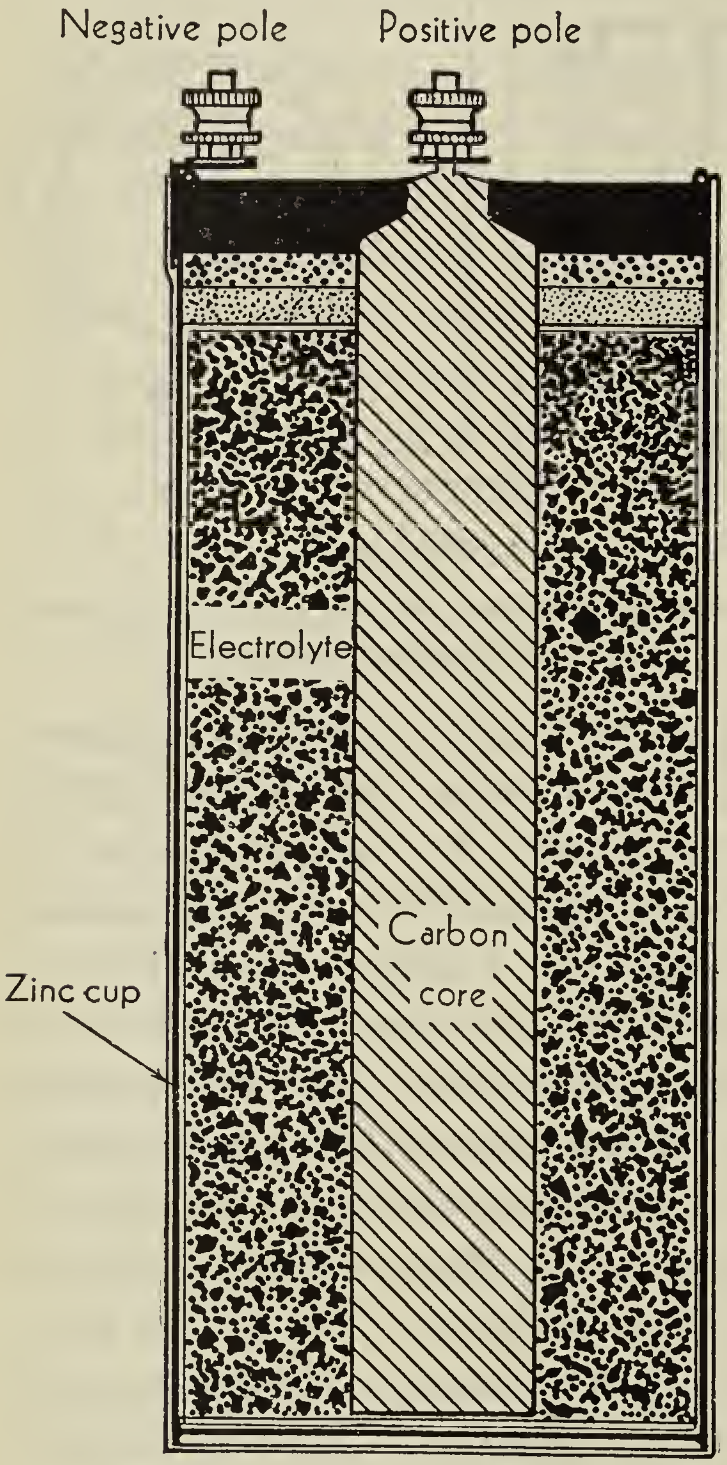


A voltaic cell

The cell (left) generates current, which is indicated by the galvanometer (right)

The voltaic cell is believed to produce an electric current as follows: Zinc (Zn) and sulfuric acid (H_2SO_4) interact to form zinc sulfate and an electric current. In doing this the acid first ionizes. By this process each of the two hydrogen atoms in the molecule gives up an electron which becomes attached to the sulfate radical. In this way two hydrogen ions (H^+) are formed and one sulfate ion (SO_4^{--}). Since the zinc atom gives up its two outer electrons easily, it thereby becomes a positive ion with two positive charges (Zn^{++}). The electrons given up by the zinc are believed to stream along the wire to the copper plate and at this point combine with the H^+ ions from the acid to form neutral hydrogen atoms. Two of these atoms now combine to form a hydrogen molecule. These molecules then bubble off as a free gas or collect on the copper plate, causing polarization. The zinc ions and the sulfate radicals combine to form zinc sulfate ($ZnSO_4$). Thus the products formed are hydrogen gas, zinc sulfate, and an electric current over the external circuit which is formed by the passage of the electrons from the negatively charged zinc plate to the positively charged copper plate. In this action the zinc plate is called the negative pole and the copper plate the positive pole of the cell.

Later the voltaic cell was greatly improved, but the principle upon which it acts remains the same. Even the familiar dry cell is but a modification of the same principle. Its construction varies, but its basic features remain the same. Essentially, as will be noted, it consists of two electrodes, one of which is zinc and the other carbon. The zinc electrode usually takes the form of a cup about $2\frac{1}{2}$ inches in diameter and 6 inches high, although smaller sizes are used in flashlights. The carbon electrode is a core placed in the center of the zinc cup (see the figure below), and the space between the carbon and the zinc is filled with the damp electrolyte and some depolarizing agent to remove the hydrogen which collects about the positive carbon electrode. The electrolyte is usually sal ammoniac (NH_4Cl), and the depolarizer manganese dioxide (MnO_2). The actual chemical reactions involved are rather complex. It will suffice to say that the electrons which form the current are liberated at the negative pole as zinc ions (Zn^{++}) are formed. Being sealed, if properly cared for, the cell retains its current-producing power for a considerable time.



Cross-section diagram of a dry cell

An Electric Current May Be Generated Mechanically. About twenty years after the "crown of cups," or first voltaic battery, had been worked out by Volta, a discovery of the utmost importance was made. One day in 1819 Hans Christian Oersted, a Danish professor, was lecturing on electricity and magnetism to his class at the University of Copenhagen. At the close of the class hour he placed the wire connecting the poles of a strong galvanic battery down on his desk beside a magnetic needle. The instant he did it he observed that the needle shifted round into a position at right angles to the current-bearing wire. That was all he saw.

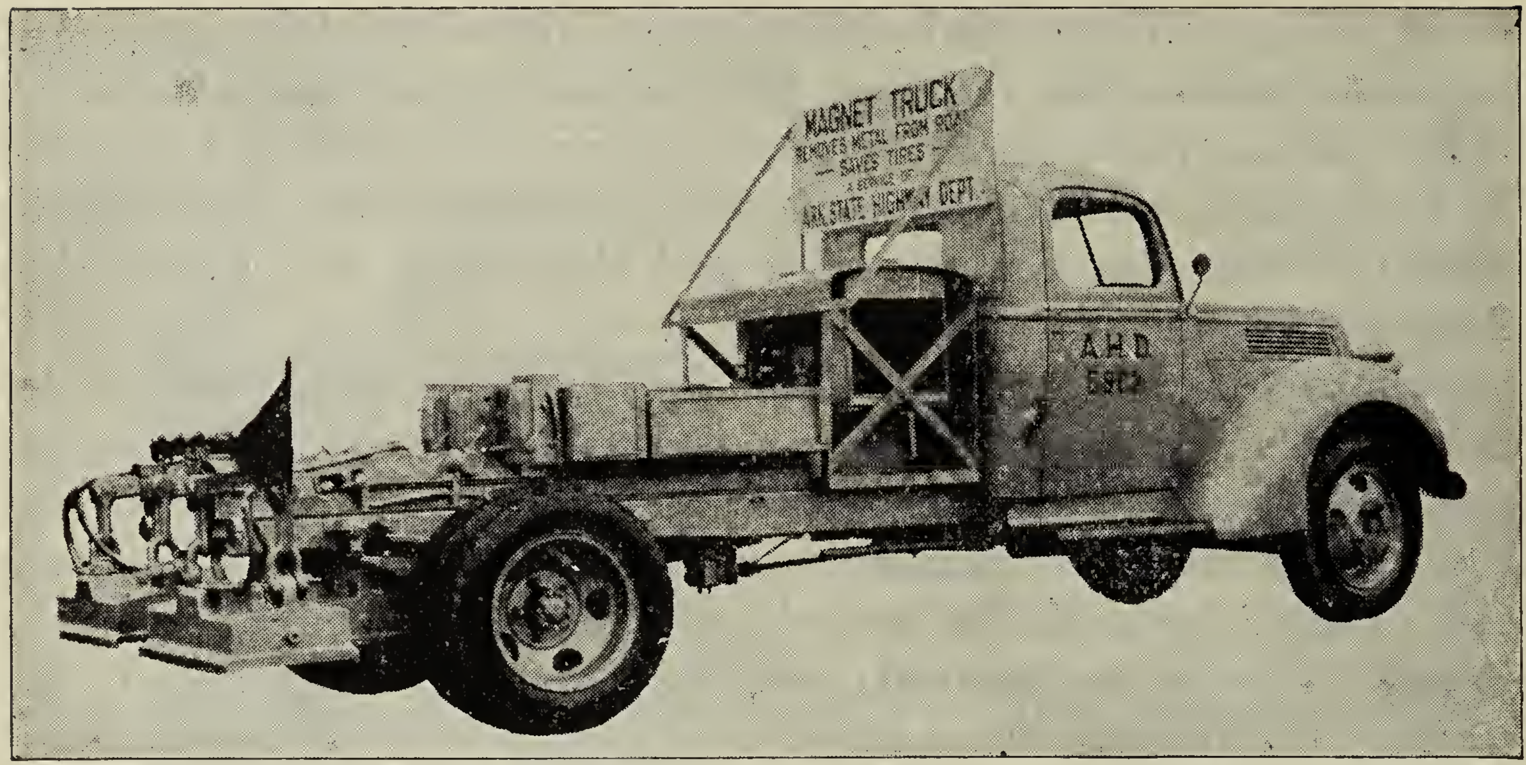
With curiosity now aroused, Oersted placed the wire on the opposite side of the compass, and the needle promptly swung so as to point in the opposite direction. Thoroughly perplexed, he repeated the movements of the wire, with exactly the same results. He continued to verify this observation until it was perfectly clear to him that the movement of the needle was caused by the presence of the current-bearing wire. He interposed glass, certain metals, water, resin, wood, even earthen jars, between the wire and the needle, but the action followed just the same. He had made a fundamental discovery: that a wire carrying an electric current is always surrounded by a magnetic field. For some time before this, workers had thought that there must be some connection between magnetism and electricity. Hans Oersted had demonstrated it.

Ampère Makes an Electromagnet. Greatly interested in Oersted's discovery, a Frenchman, André Ampère, took up the study of the magnetic properties of wires bearing electric currents. He found that the magnetic field about a wire was greatly increased if the wire was twisted into the form of a coil. Going a step farther, he inserted a soft-iron bar through the inside of the coil and discovered that he could in this way produce a powerful magnet. The reason the lines of force are condensed into a stronger field is that iron and steel are magnetic substances and provide a better and easier path for the magnetic lines of force to flow through than does the air. In other words, the lines of force follow the path of least resistance, which in this case is the iron bar.

Another important observation made was that the soft-iron bar became demagnetized the instant the current was cut off. Ampère, through the sheer power of his own genius, was uncovering a whole series of electromagnetic discoveries indispensable to the newly developing science. The most significant of all these was the electromagnet. It was no mere coincidence, then, that the unit of electric current used today came to be called the *ampere.*

Projecting his ideas beyond the limits of possible demonstration, Ampère formulated a theory to explain the magnetic lines of force exhibited by any magnet, even a permanent one. He conceived a magnet to be produced primarily by the action of an electric current. He thought that each particle in a magnet was in some way surrounded by a miniature equatorial electric current which produced the magnetic poles. He even attributed terrestrial magnetism to currents passing round the earth parallel to the equator. It will be seen that Ampère a hundred years ago had exactly the same ideas as to the cause of magnetization which we hold today. The only difference is that he considered electric currents to be coursing round the polarized particles, while we conceive a stream of electrons to be coursing about them. But when we remember that electrons are nothing more than a stream of negative charges spinning about the atoms, all fundamental differences between the two views vanish.

Essentially Ampère and modern physicists are in agreement. Two years later (1825) William Sturgeon, a self-made scientist, bending a bar of soft iron into the shape of a horseshoe and wrapping it with wire insulated by a coat of



Arkansas Highway Department

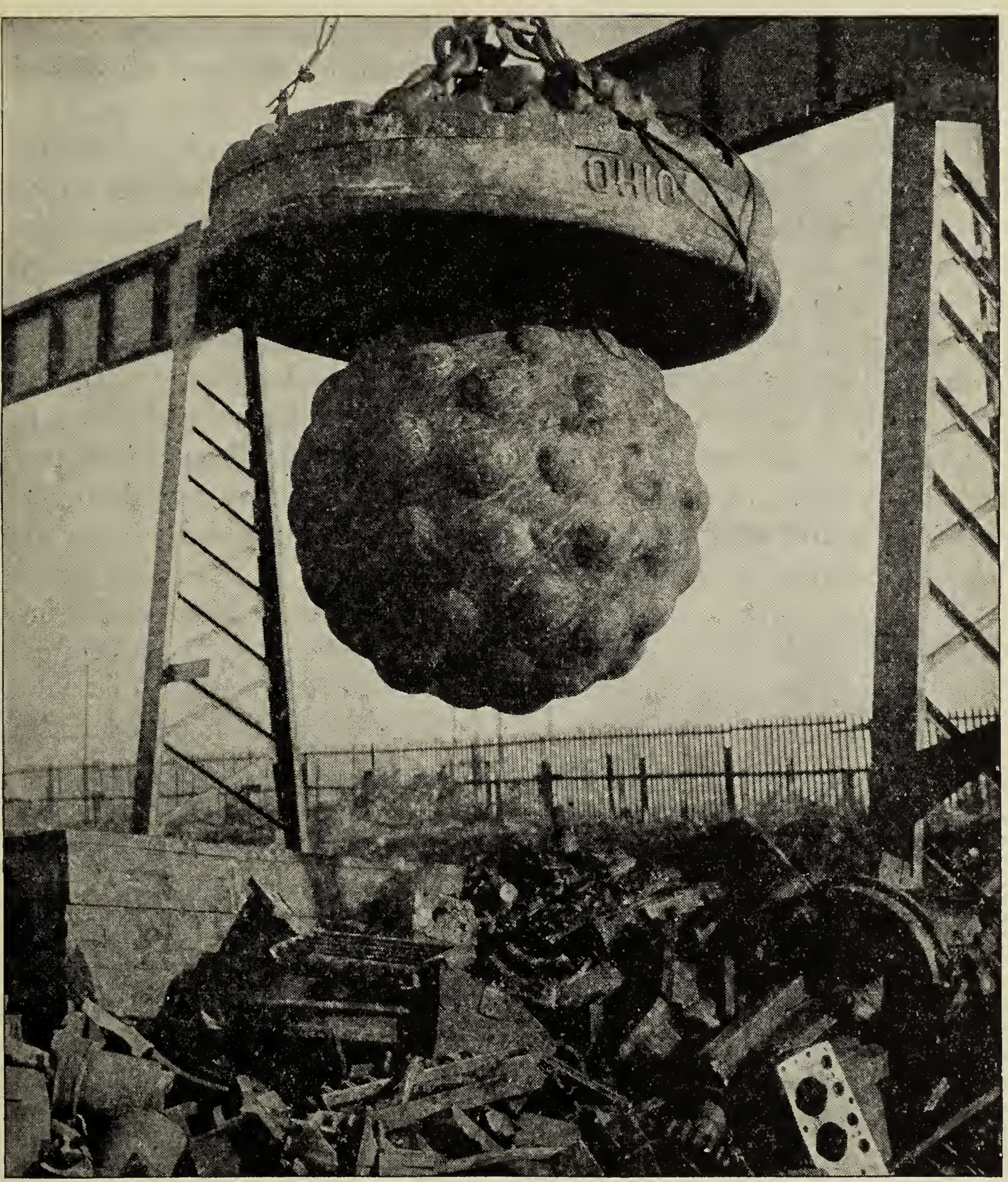
Electromagnets as road-sweepers

The electromagnets shown at the rear of this truck are used to remove metal objects from the highways in Arkansas

varnish, made a magnet capable of lifting a nine-pound weight. This magnet, without doubt, may be considered the forerunner of those powerful electromagnets now used to move steel rails, lift heavy weights, and unload scrap iron.

More recently electromagnets have been used in surgery to remove bits of metal that had become embedded in an eyeball through accident. Not long ago a mill employee at Providence, Rhode Island, by accident had several tiny needles embedded in his finger, so that infection developed. His finger was placed in the field of a powerful electromagnet by the surgeon, and the six needles were drawn out in this manner within five minutes. In North Dakota and Arkansas a strong, appropriately shaped electromagnet has been employed as a "road-sweeper" to remove nails and other metal objects from the highway. The sweeper, eight feet wide, was operated over a total distance of 3364 miles of roadbed during 1936. Within this twelve-month period it picked up 36,110 pounds of assorted metal, or an average of 10.7 pounds per mile. Doubtless many an unwelcome automobile-tire puncture was averted by this ingenious expedient.

Electricity Is Made to Do Work. When Oersted found that a magnetized needle would move under the influence of a passing electric current and Ampère discovered how to make powerful electromagnets, they were on the threshold of another momentous discovery. Heretofore the only kinds of electricity known were frictional electricity and electricity generated by a galvanic battery. The first kind was practically useless except as the manifestation of



A 55-inch electromagnet

This magnet carries a "skull cracker" used to break scrap iron

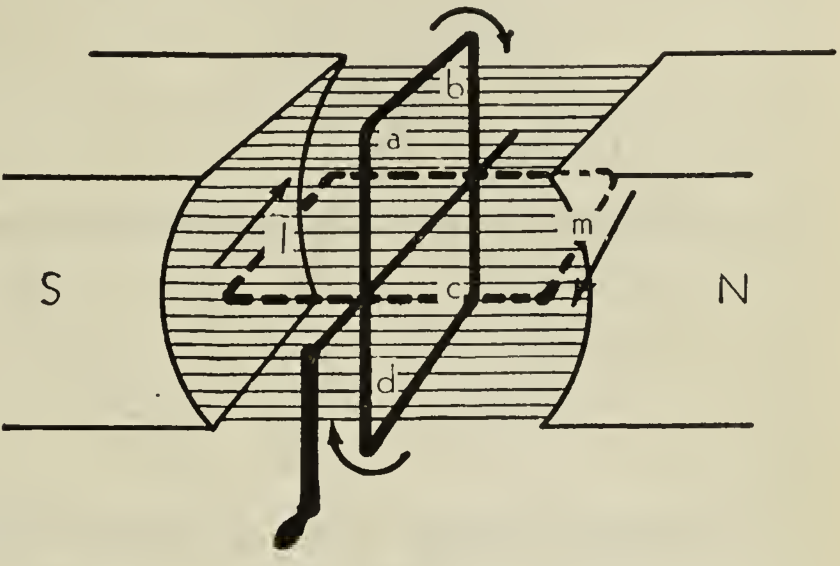
an interesting natural phenomenon; the second might have been turned to considerable use as a source of electric current (as, indeed, it was, in connection with the telegraph and the telephone). As a source of power, however, to do the multitudinous tasks that modern industry lays upon the shoulders of electricity, the amount of current that could have been generated by the chemical cell would have been a mere bagatelle. A still better way of producing electricity was to be unearthed as the electrical drama proceeded. The chief actor in this scene was a young Englishman by the name of Michael Faraday.

Faraday has been called the greatest investigator of the nineteenth century. He was born in humble circumstances and lived in poverty during all his earlier life. As he approached manhood, he became a bookbinder by trade, and in this way came in contact with a considerable amount of reading material. He found especial delight in articles on natural science, which he read with great avidity when his working hours were over. A friend, noticing his deep interest in science, invited him to attend the last four of a series of lectures which Sir Humphry Davy, the great chemist, was delivering in London. So inspired and delighted was young Faraday by these lectures that bookbinding from then on lost all its appeal to him and became mere drudgery. A short time afterward he wrote to Davy, expressing his desire to enter the field of science and to do work in Davy's laboratory.

That Davy received this appeal with great consideration has proved of immense value to the whole world. He wrote young Faraday, "I am far from displeased with the proof you have given me of your confidence." A few days later a liveried footman in Davy's coach drew up before the humble home of the Faradays and invited young Michael to a conference with the great chemist. The result was that Faraday became Davy's assistant. Trained under Davy and further stimulated by an extensive tour of the Continent with his master, where he met many of the leading scientists of Europe, Faraday plunged into the study of electricity, which at that time had been brought into great prominence by the discovery of Oersted.

Faraday put this question to himself: If a magnetic needle can be made to turn halfway round by an electric current and then be made to turn back the other way when the current is changed, why, if the current is properly controlled and shifted in direction, cannot the needle be made to turn all the way round and, in fact, be made to continue rotating? Faraday worked intently on a device to accomplish this; and one day in 1831, after much experimenting, he completed his apparatus and turned on the current from a galvanic battery. Suddenly the indicator gave a jump, started whirling, and continued to rotate. In reality Faraday had arranged two such indicators. When he saw them both whirling around, he was so beside himself with joy that he is said to have shouted, "There they go! There they go!"

He continued his work and soon achieved the reciprocal result of producing an electric current. He did this by rotating a pivoted conductor in a magnetic field in such a manner as to cut the lines of force. Here was the first generator invented by man—a simple laboratory device, unimpressive in its mechanism, yet destined as a source of power to revolutionize society. Faraday is said to have demonstrated his whirling device on one occasion to the illustrious Gladstone, who innocently asked of what use it might be — an evidence that even eminent statesmen may not comprehend the importance of great discoveries outside their own field. Faraday replied, "Why, sir, you will soon be able to tax it." Tyndall, another celebrated English physicist, wrote:



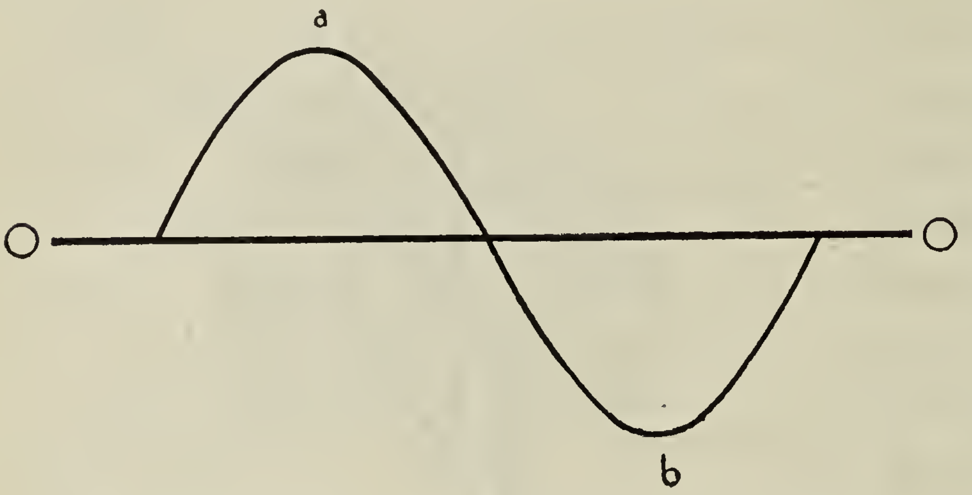
Simple diagram to illustrate the principle by which the electric generator works

> I cannot help thinking . . . that this discovery of magnetoelectricity is the greatest experimental result ever obtained. It is the Mont Blanc of Faraday's own achievements. He always worked at great elevations, but higher than this he never attained.

However complex and bewildering the mechanism of a big modern electric-power plant may seem when one views it, the fundamental principle behind all the tremendous amount of electrical energy being produced is the simple one worked out by the ingenious Faraday in his laboratory at London. Generators have been enlarged, electromagnets improved, armatures perfected, and transmission lines multiplied, but the fundamental principle remains the same: a current is generated by the influence of magnetic fields on moving coils of wire. It is little wonder, then, that when Sir Humphry Davy was asked what his greatest discovery was, he replied without a moment's hesitation, "Michael Faraday." At this point it will be of interest to consider Faraday's principle further as applied in the simple generator.

The Generator Transforms Mechanical Energy into an Electric Current. The generator is a device to transform mechanical energy into an electric current by means of an electromagnetic field. It may be reduced to very simple terms. If one rotates a loop of copper wire between the opposite poles of two permanent magnets, a feeble current will be generated as the wires cut through the magnetic lines of force. This can be detected by setting a delicate galvanometer in a closed circuit of which the loop is a part.

To illustrate: Let the copper-wire loop *abcd* (see figure above) be rotated between the magnetic poles as indicated. When the plane of the loop is perpendicular to the magnetic lines of force, as shown in the diagram, the wire of the loop is cutting practically no lines of force, and there is no electromotive force, as electrical engineers term it, developed. In other words, the emf (electromotive force, or difference of potential) is zero. Now imagine the loop to turn clockwise one fourth of the way around. As it moves toward the ninety-degree position, the wire cuts the magnetic lines of force more rapidly and the current grows in strength until the sides reach the points *m* and *l*, respectively, when the maximum number of magnetic lines of force is cut and the emf of the current reaches its highest point. As the coil continues to rotate through the next quadrant, the number of magnetic lines of force cut, it is evident, will constantly decrease, and the difference in potential will fall until the loop has described exactly a quarter of a circle and takes a position with its plane again perpendicular to the lines of the magnetic field. At this point the emf has once more fallen to zero. Now as the loop continues its turn through the next half of the circle, the very same results follow as in the first half-turn, with one exception. In this case the sides *ab* and *cd* of the coil are moving under the influence of the S pole and the N pole, respectively, of a magnet, which is exactly the reverse of the condition prevailing during the first half-turn. This change in the position of the lines cut effects a complete reversal in the direction of the flowing current the instant the second half of the rotation is begun. The results are graphically represented in the figure above. From this it is evident that during a complete turn two things of primary importance take place: first, the current flows in one direction the first half of the period of rotation and in the opposite direction the second half, producing what engineers call an alternating current;[1] secondly, the emf starts from zero, increases to a maximum, and again falls to zero during *each* half-turn. We have here the principle employed by the generator.



The curve representing the emf produced in a generator

The simplest generator that can be constructed is a single loop of conducting wire attached to a shaft in such a manner as to be capable of being rotated in a magnetic field, and provided with two collars, to one of which each end of the loop is attached. Electrical engineers call this looplike, rotating conductor an *armature.* The collars turn with the central shaft, to which they are made fast, and usually copper or carbon contacts, called brushes, complete the connection between the revolving collars and the external circuit.

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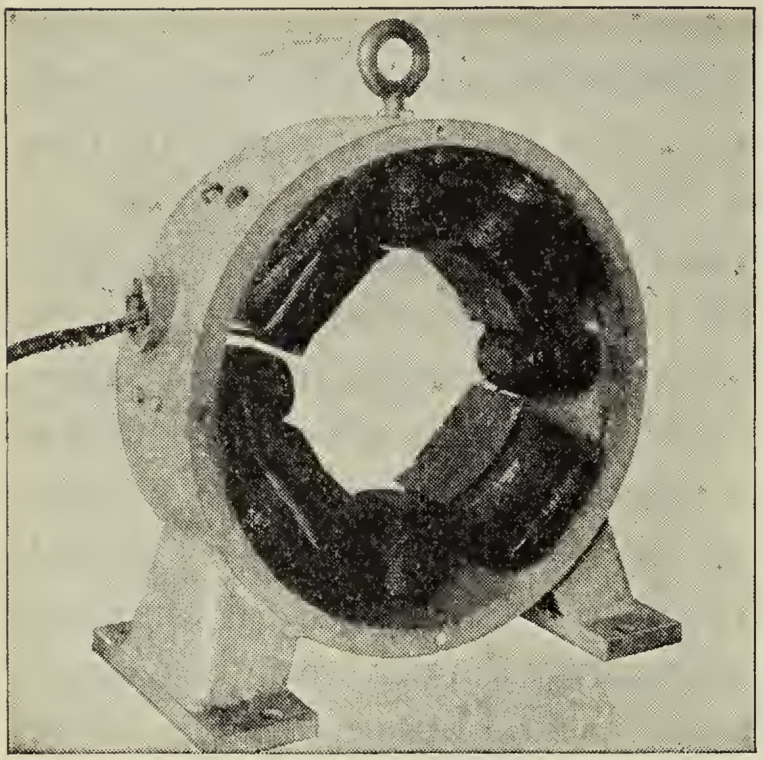
[1] When used as an adjective, abbreviated a-c, as an a-c transformer.

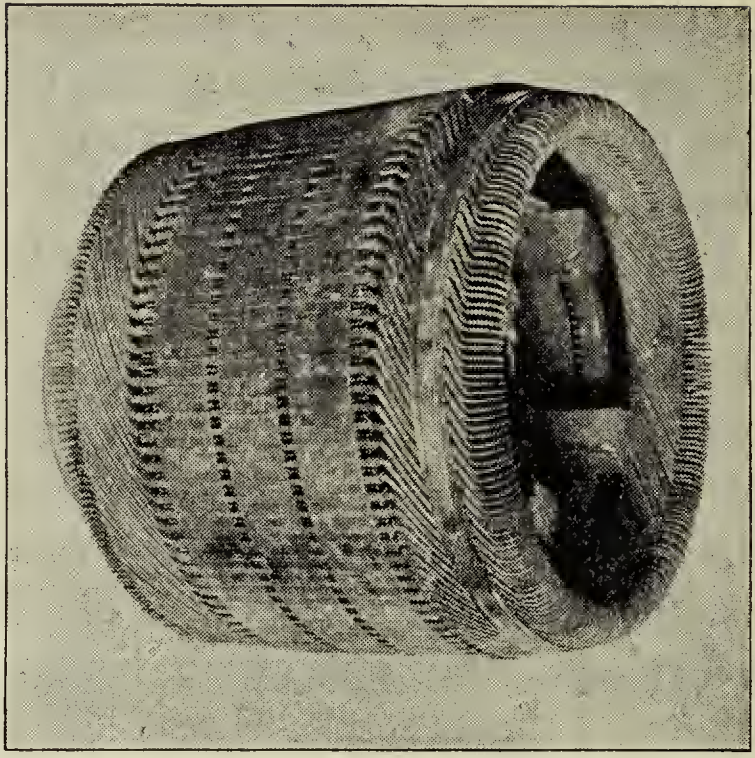
The Voltage and Amperage of a Current Are Related. When electricity flows as a current, the magnitude of that current is determined chiefly by two factors. These factors are the *voltage* and the *amperage.* A third factor, which affects the voltage and amperage, is the resistance offered to the flow of the current. The *ampere* is the unit which expresses the rate of flow; the *volt* is the unit of electrical pressure, or potential difference. A boiling teakettle has been used to illustrate the difference between amperage and voltage. The kettle may be boiling vigorously and much steam be generating, but if the lid is off the steam escapes easily. No pressure develops within the kettle, and the steam rolls out in great quantities. On the other hand, if the lid of the teakettle is securely on and the spout is plugged so as to leave a very small opening, the steam cannot escape as fast as it is generated. This causes pressure to back up inside the kettle, which in turn pushes the steam out with greater force. Not nearly so much steam may be expelled in a second, but what does issue is literally blown out by the pressure behind it. A similar relation exists between the amperage of an electric current and its voltage. When little resistance is interposed, the current, like the steam in a teakettle when the lid is off, flows easily from its source, causing the amperage to be high, but the voltage low; when the resistance to the current is increased, the electricity cannot flow readily. As a result, the electricity fed in continuously from its source (generator or battery) tends to accumulate and thus increase the electrical pressure, or voltage, behind the current. From this it may be seen that a current may have a high amperage and a low voltage or a low amperage and a high voltage. One may be increased and the other decreased by varying the resistance.

The Electromotive Force of a Current May Be Varied. It now becomes obvious that the electromotive force of an electric current may be modified by conditions in the generator. If powerful electromagnets are arranged to form the magnetic field, instead of permanent magnets, the strength of the field is commensurately augmented. Likewise, if the number of electromagnets be increased to four or six or even more, as is usually done, a multipolar magnetic field is produced, which greatly multiplies the lines of magnetic force. As the armature turns, the number of lines of force cut will be increased, and this raises the amperage of the current. A similar effect may also be achieved by increasing the number of wire loops on the armature. In



General Electric Company

Field magnets of a multipolar dynamo



General Electric Company

A drum armature with many loops of wire

building armatures for great, power-producing generators many loops of wire are used instead of one, each loop being effectively insulated from the others. The whole forms a sort of drumlike cylinder. The loops are set in place in such a way that when one side is approaching an N magnetic pole, the opposite side is simultaneously approaching an S magnetic pole. By using many loops in the armature more lines of force are cut per unit of time, which increases the amperage of the current. The result is something like that gained by increasing the number of cylinders in an automobile.

In contrast with this, if the revolution of the armature is speeded up, this action does not affect the strength of the magnetic field. It does, however, change the rate per second at which the lines of force are cut, and this change increases the electrical pressure, or voltage, of the current. The usual speed of the ordinary commercial generator is so regulated as to produce 120 reversals in the current per second, or what is known as a 60-cycle current. This is the type of alternating current furnished homes and industrial plants by many power companies.

An Alternating Current May Be Changed into a Direct Current. The flow of electrons produced by a galvanic battery is always in one direction, that is, from the zinc plate to the copper plate. For this reason it is called a *direct* current[1] to distinguish it from the alternating current just described. This direct current produced by batteries was the first type of current that electrical engineers learned to use. It found large application particularly in connection with the rapidly extended telegraph lines of the latter part of last century.

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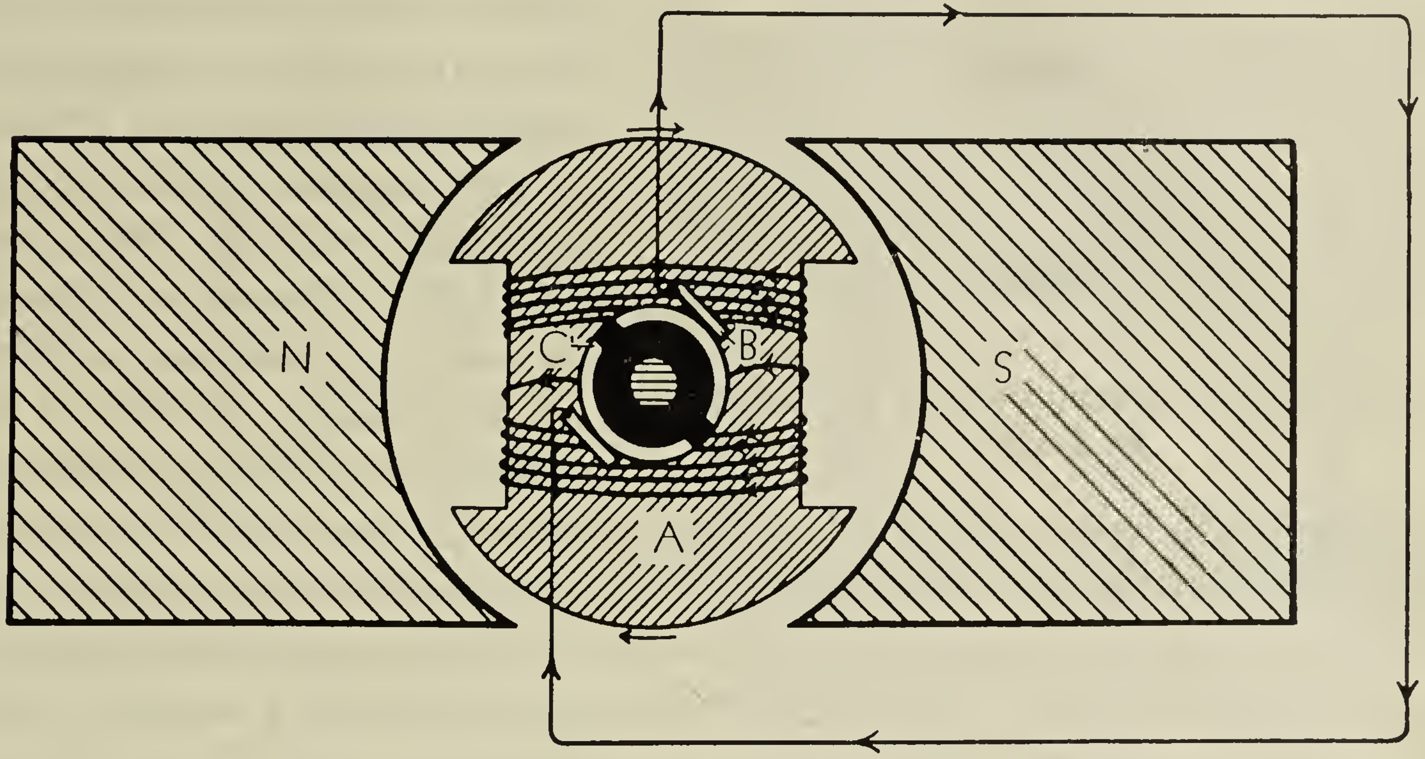
[1] When used as an adjective, abbreviated d-c.

When the electric generator was invented, electricians were thoroughly puzzled regarding the use of the mechanically produced current. For we have found that a generator can produce nothing but an alternating current on the armature. How to make use of a current that flows one way for an instant and then reverses itself and runs in the opposite direction was a perplexing problem. For a time it looked as if there would be no market for the alternating current.



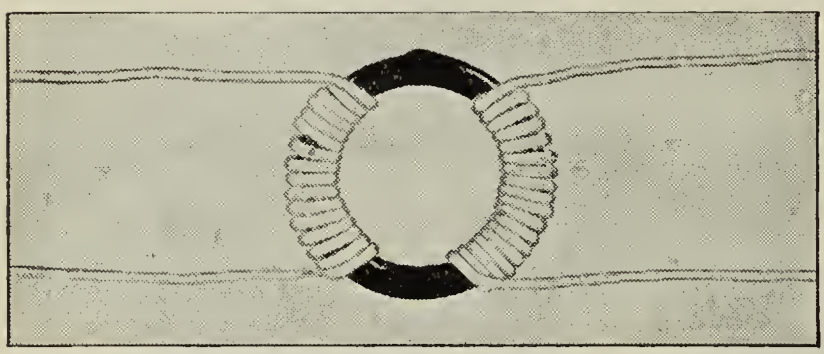
A two-segment commutator

A, armature; *B*, brush; *C*, commutator segment

But at this apparent impasse relief came by the further discovery of a simple device called a *commutator*. In its simplest form the commutator consists of a ring of carefully insulated copper segments arranged in pairs, the members of each pair being placed directly opposite each other on the armature shaft. Each pair is further connected with the extremities of a single-armature coil. Brushes are so adjusted to the commutator segments that the instant the direction of the current in the coil is reversed, the brush taking the current off slips to the other one of the opposite pairs of segments. In this way the current is kept flowing in one direction, as in the case of the galvanic battery, and we have what is known as a direct-current generator.

Electric motors and other appliances of all kinds have been developed which use alternating current. Indeed, most of the electricity used both by industry and private parties today is utilized in the form of alternating current.

Electric Currents May Be Induced. Most of us have seen the iron "boxes" bolted to the electric-light poles, and doubtless many of us have wondered what they were. They are devices employed for the purpose of reducing the voltage of that portion of the current to be diverted from the main transmission line and led into our homes for domestic use. Without these devices current electricity taken from trunk lines could not be used in dwelling houses. It would be too dangerous, because its high potential would, like the thundercloud, force the current through the ordinary insulators used in a dwelling house, set fire to the building, and endanger human life.



An induction apparatus similar to that used by Faraday

For the fundamental principle underlying these devices we are indebted to Michael Faraday again. Faraday, after trying out several other schemes, took a soft-iron ring and wrapped each half with a wire, letting the ends from each spiral extend out free. To the ends of one coil he attached a battery; to the other, a galvanometer. Much to his encouragement, he noted that the instant the circuit connected with the battery was closed or opened the galvanometer needle fluctuated and then settled back again to a position of rest. But he could not understand why the induced current was momentary only. While working on this new principle he wrote to a friend: "I am busy just now again on electromagnetism, and think I have got hold of a good thing, but can't say. It may be a weed instead of a fish that, after all my labour, I may at last pull up."[1] He and Henry of Johns Hopkins University continued to work in this field independently and unknown to each other for several years. Both worked on the principle of electrical induction.

As a result largely of the genius of these two men, then, we have what is known as the electrical transformer. In reality its principle is not new. It is but an extension of the principle of induction employed in the generator. If a hollow cylinder is wrapped with insulated copper wire the ends of which are made fast to the binding posts of a galvanometer, and a second cylinder wrapped with a similar coil attached to a battery is slipped within the hollow of the first cylinder, a momentary, feeble current detectable by the galvanometer is induced on the outer coil the instant the inner coil is slipped into place. If the inner coil in turn be removed, a reverse current is induced the moment it is pulled out. In this case the inner, or current-bearing, coil is called the *primary coil*; the outer one, upon which the current is induced, is known as the *secondary coil*. As long as the coils remain stationary, no effect is produced.

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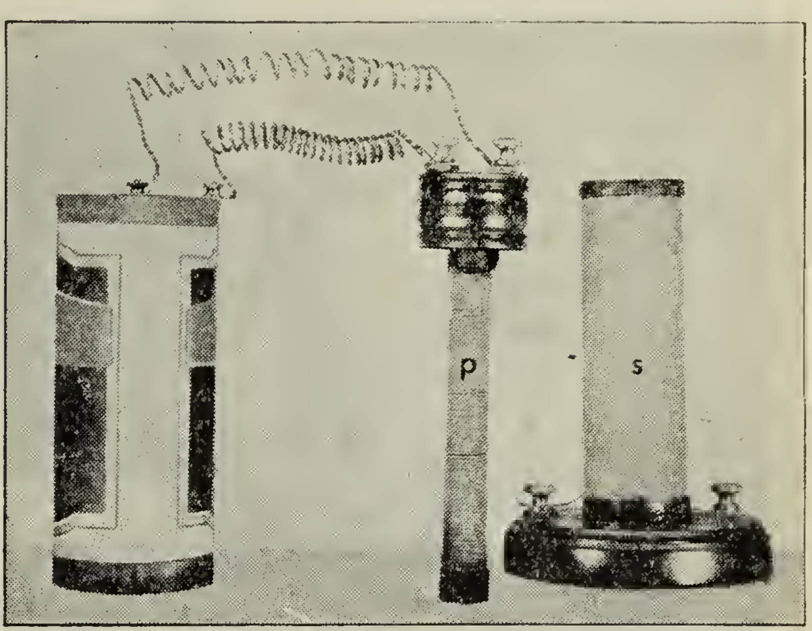
[1] Bence Jones, *Life and Letters of Faraday*, Vol. II, p. 3. By permission, Longmans, Green, and Company, publishers.

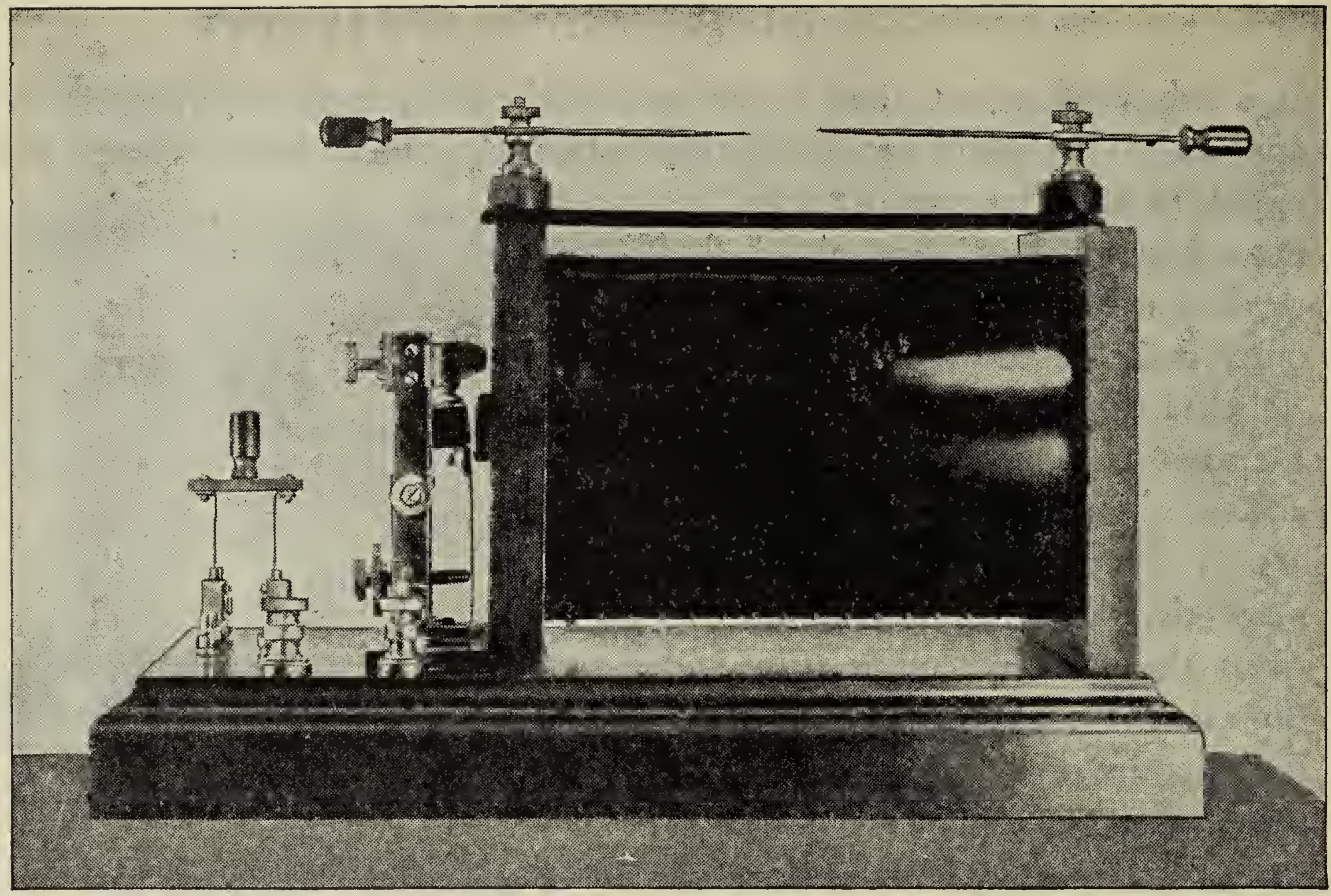
It is only when one of them is moved that the current on the secondary coil appears. What really happens is this: when the primary coil is slipped in or out of the secondary one, the magnetic lines of force surrounding the first are cut by the wire of the outer coil (see the figure at the right), just as they are cut by the rotating loops of a generating armature. In this way a secondary current is produced. The magnetic lines are cut one way when the primary coil is being slipped into place and are cut in the opposite direction when it is being taken out. The current on the secondary always flows in the opposite direction from that of the primary. This accounts for the change in direction of the induced current as indicated by the opposite shift of the galvanometer needle. The device which has just been described and explained is called a demountable induction coil.



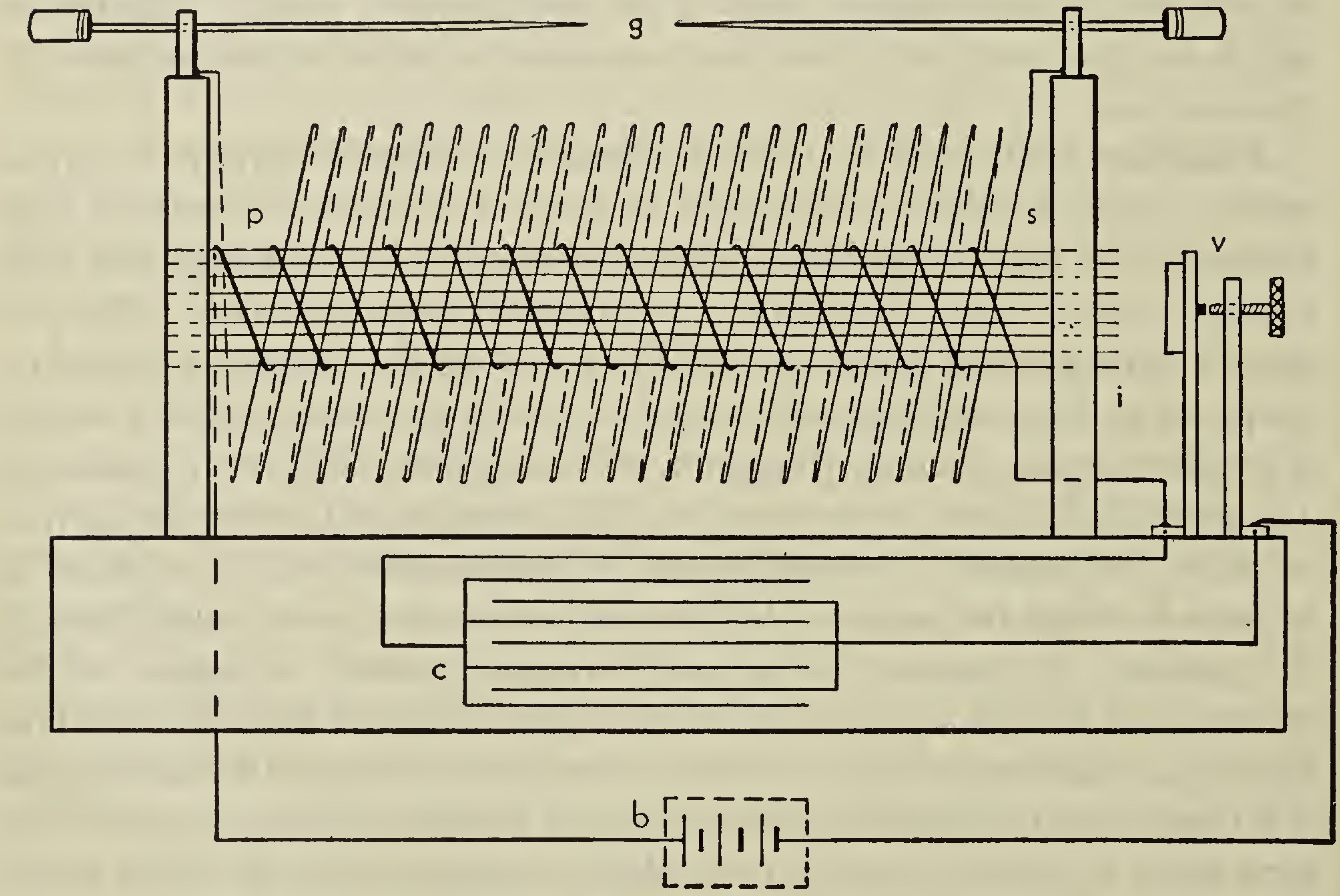
A coil used to demonstrate the principle of induction

P, primary coil; *S*, secondary coil

Induction Coils May Be Used to Transform Electric Currents. Permanently mounted induction coils may be used to transform currents of high amperage and low voltage into induced currents of low amperage and high voltage, or vice versa, according to the type of current desired. The permanent induction coil consists essentially of a strong electromagnet formed by wrapping well-insulated copper wire about an iron core composed of a bundle of small iron rods, a bundle of separate rods being more effective in producing a magnetic field than a single large bar. This primary coil carries the current to excite the magnet. A secondary coil of well-insulated wire is so placed as to be well within the magnetic field formed when the current passes through the primary. In practice it is generally wrapped around the outside of the primary coil in such a way as to be thoroughly insulated from it, the whole forming a stationary system. In such permanently mounted induction coils it is obvious that neither the primary nor the secondary coils can move. The same effect is achieved, however, by placing a make-and-break device in the primary circuit. In this way the magnetic lines of force which cut the secondary coil are rapidly formed and then suddenly interrupted. The result is a pulsating current, produced on the secondary coil by induction.



Induction coil



A diagram showing the principle of the induction coil

b, battery; *c*, condenser; *p*, primary coil; *i*, induced magnet; *v*, vibrator; *s*, secondary coil; *g*, spark gap

If a current of higher amperage but lower voltage is to be transformed into one of lower amperage and higher voltage, as is often the case, the primary coil is composed of relatively few turns of large wire, while the secondary coil is wrapped with many turns of fine wire; the larger the wire and the fewer the turns on the primary, and the smaller the wire and the greater the number of turns on the secondary, the higher the voltage of the induced current. This type of current is desired when it is to be forced out against great resistance. By the use of such an induction coil, a spark—literally a miniature streak of lightning—two or three inches long may be made to crash through the high resistance of the air between the points on top of the coil which form the extremities of the secondary circuit.

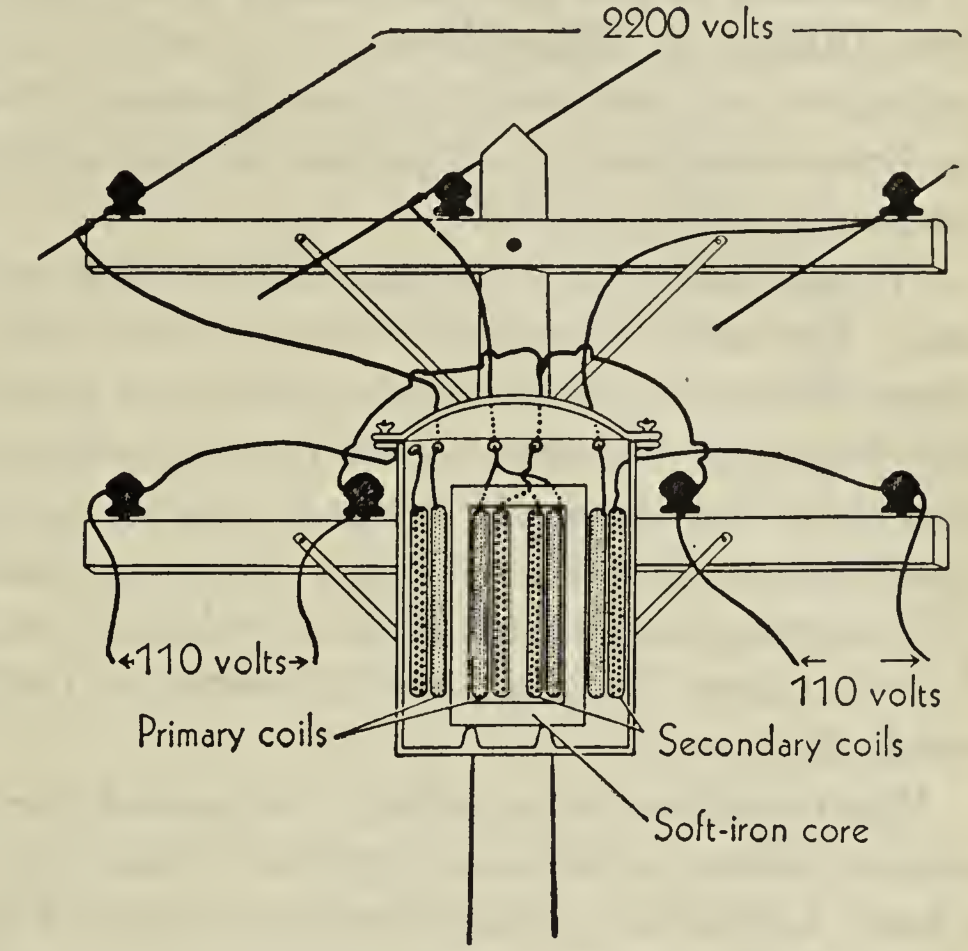


Diagram to illustrate the principle of the transformer

It is evident, however, that no current can be induced by a magnetic field as long as the magnetic lines of force and the wire upon which the induction is to take place both remain still. One or the other must move. In the generator this result was accomplished by having either the coils of the armature or the magnets producing the magnetic field rotate. In the induction coil it is achieved by a make-and-break device. It has been found that the same results can be obtained by having the current on the primary alternated in direction, which has the same effect as that of a very rapid make-and-break device.

We are now in a position to understand the principle of the iron boxlike structures bolted to electric-light poles. In reality they are nothing but big induction coils, although they are known among electricians as transformers. Their purpose is to transform an alternating current of a voltage too high to be used safely into one of such a voltage as to be conducted into our homes with safety. Transformers of this type are known as *step-down* transformers; those employed to increase the voltage of a current are called *step-up* transformers. In transformers the insulated coils are usually packed in oil, which, being a nonconductor, is used to give further protection against possible short circuits.

Resistance to the Flow of Electric Current by Various Conductors Has Been Utilized in Many Ways. In an earlier part of the chapter electrical conductors and nonconductors were discussed. Now that current electricity has been considered, it will perhaps be profitable to follow this principle of conduction a little farther.

We have found that substances differ widely in respect to electrical resistance. The unit of electrical resistance is the *ohm.* It is named after Georg Simon Ohm, who worked on the problem of electrical resistance over a hundred years ago. To define the ohm in exact physical terms is a technical task. We can get some notion of this unit, however, by saying that a tiny thread of liquid mercury 1 square millimeter in cross area and 106.3 centimeters long at 0° C interposes a resistance of about 1 ohm to the flow of an electric current. A 50-watt lamp "burning" on a 110-volt circuit offers a resistance of approximately 242 ohms.

When resistance to a current is interposed, the electricity is compelled to do work to flow past this resisting force. This work manifests itself in the form of heat. Utilization of this principle is the basis of all electric heating elements, such as electric stoves, toasters, irons, water-heaters, curling irons, and warming pads. Even the filament in the electric light is illuminated because of the heat generated by its resistance to electrical flow.

Many heating elements of great efficiency have been developed. One of the very best is a nickel-chromium-steel wire which is used either in the round or the ribbon form.

Closely related to the principle of resistance is the use of *fuse plugs.* These plugs are used extensively as a safeguard against the heating effects of an overflow current of electricity. For example, the electrically equipped home is wired so that the lights and appliance plugs when in use offer such resistance to the current flow that its amperage is held down within the limits of safety. But let a short circuit occur in the house wiring, and much of the resistance is cut out. Consequently the current rushes through this path of lowered resistance, and the rate of flow, or amperage, is greatly increased. An overflow of electricity can also occur from a bolt of lightning or from contact with a power wire on the external circuit. An excessive rise in amperage, such as now occurs, tends to heat the house-circuit wires to the point of danger. Many disastrous fires have occurred in this way. Moreover, such a current, if passed through electric appliances, may burn out the heating element or motor.

As a safeguard the home is supplied with a fuseplug, or overamperage protector. This is often just a porcelain-insulated plug which screws into a socket and thus completes the circuit across the socket gap. This plug contains an amperage-rated conductor which can carry just so much amperage before it melts and breaks the circuit. Fuses for 110-volt house circuits are standardized at about 15 amperes. Heavier circuits for electric ranges are fitted with fuseplugs as high as 60 amperes. No one should ever close a fuseplug gap with a piece of metal, as is sometimes done. By this means one closes the circuit and permits the current to flow, but removes the only safeguard if the line should be struck by a bolt of lightning or a short circuit should occur in the wiring.

Electricity, as we have found, is used chiefly either for its heating effects, due to resistance, or for its electromagnetic effects. Regardless of the purpose for which it is used, it must be measured. It is only in this way that it can be bought and sold. The unit of electric power (rate of doing work) is called the watt. This unit is defined as the product of a volt and an ampere. Thus a 110-volt current flowing at the rate of 50 amperes will supply approximately 5500 (110 × 50) watts of electric power. The incandescent lamps used in residences and other buildings consume current in terms of watts and are rated on this basis. An idea of the illuminating power of a lamp may be gained from its wattage consumption; for example, most of us are aware of the different degrees of illumination to be had from 40-watt, 60-watt, and 75-watt lights.

The watt is a relatively small unit of measurement. If it were used commercially, power companies and users of electrical energy would have to deal with large figures to express the quantity of electric power consumed. To avoid this inconvenience, current is measured commercially in terms of kilowatts (Greek *chilioi*, "thousand" + watts); a kilowatt is 1000 watts.

But to measure and sell electric power equitably one more factor must be considered—the factor of time. It is obvious that two consumers might each be using electric power at the same rate; but if one of them used the current twice as long as the other, he should pay twice as much. To meet this need the unit kilowatt-hour has been adopted. It means, as the term itself indicates, the use of electrical energy at the rate of 1 kilowatt for 1 hour. Electric current, then, is bought and sold in terms of kilowatt-hours instead of kilowatts.

Questions for Study

1. How does the modern conception of the structure of matter enable one to advance a plausible theory regarding the cause of magnetism in lodestones and permanent magnets?

2. In what ways has magnetism been an invaluable aid to man's progress?

3. How many everyday uses of magnetism can you think of?

4. What is one of the most common evidences that the earth is a giant magnet?

5. It has been suggested that the earth is surrounded at some distance by an electrified atmospheric sphere. What relation might this sphere have, if it really exists, to the magnetic condition of the earth?

6. What are some of the ways in which static electricity is related to everyday experience?

7. How is static electricity believed to be related to the modern conception of the atom?

8. What is the modern explanation of the nature and cause of lightning?

9. How is the lightning rod believed to protect buildings and other objects?

10. If lightning rods are used, why should they be well grounded in damp earth?

11. What is the best explanation you can offer to explain the fact that when a body is charged with static electricity, the charge always resides on the outer surface?

12. How does the modern theory of atomic structure aid in explaining the electrically conducting and nonconducting properties of different substances?

13. How does the modern conception of atomic structure assist in explaining the production of an electric current by chemical reaction?

14. Why would it be impossible to use electromagnets in moving heavy iron objects or to use the electric motor to do work if the molecules of soft iron were not readily polarized and depolarized?

15. Why cannot electric current be profitably transmitted more than about 300 miles?

16. Why can direct electric currents be transmitted much more economically than alternating currents?

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CHAPTER TWENTY

The Applications of Electricity Are Numerous

The Electric Motor Has Been a Potent Factor in This Industrial Age. When Michael Faraday perfected the simple generator in 1831, it was like raising the curtain on a new power age. Before that time electricity could be only produced by friction machines or by chemical cells. Either means was comparatively slow, limited in capacity, and entirely inadequate. But with the generator, as later perfected, conditions were changed. A convenient source of abundant power had arrived, for here was a machine that could be hitched to a steam engine or a water wheel and be made to produce great quantities of current electricity. Then, by building transmission lines, this energy might be carried great distances from the generating plant to the private home, the retail shop, or the factory. Now a supplementary mechanism was needed—one that could convert electrical energy at the end of the transmission line back into mechanical power and use it to drive machinery. Happily the need was soon fulfilled. Indeed, the principle of the electric motor was discovered long before electricity was generated in sufficient quantities to become of commercial importance.

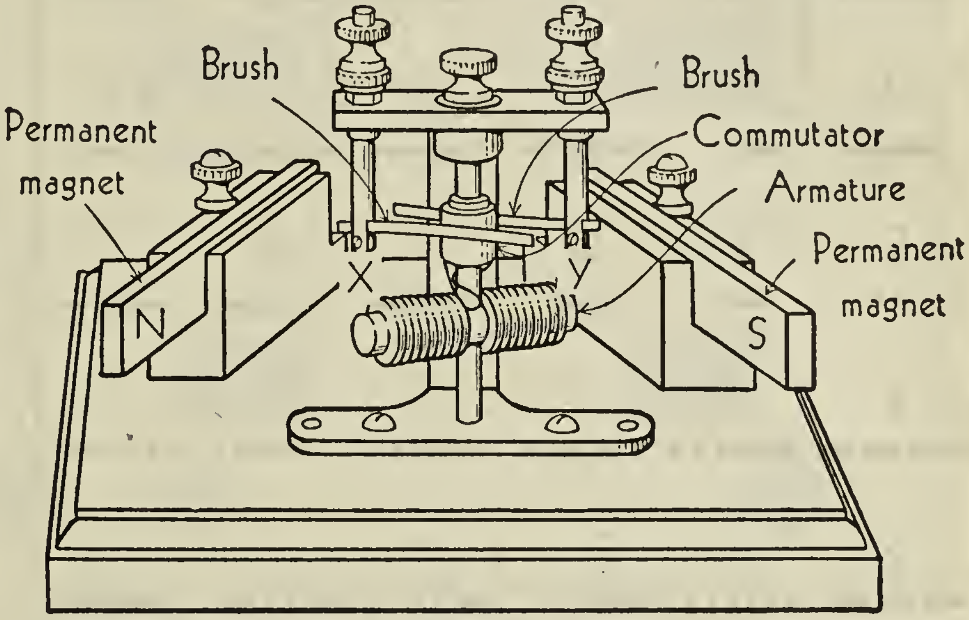

Diagram of a simple motor[1]

The fundamental principle underlying the construction and operation of the motor is a simple one. It is based upon the fact that like magnetic poles repel each other and opposite poles attract. The illustration above shows a very simple motor in which permanent bar magnets furnish the magnetic field. This motor has a commutator and may be run by a direct current supplied from a dry cell. If the cell is properly connected, then as the current flows in through the brushes and the commutator it will convert the armature into an electromagnet with its south and north poles, respectively, at *X* and *Y*. Under this condition the poles of the electromagnet will both be attracted, and the armature will rotate. If, just as the circular momentum carries the armature poles past their respective permanent magnets, the current in the armature is reversed by the commutator, *X* will be converted into a north pole and *Y* into a south pole. Now both *X* and *Y* will be repelled by the adjacent permanent magnets, which will keep the armature revolving. As the armature continues to rotate, *Y* will come more and more under the attractive pull of the north pole of the permanent magnet, and *X* will fall under that of the south pole. These pulls will tend to keep the armature rotating. Then, just as *X* and *Y* pass their respective magnetic poles a second time, the current in the armature is reversed again by the commutator, and the motor will be kept running.

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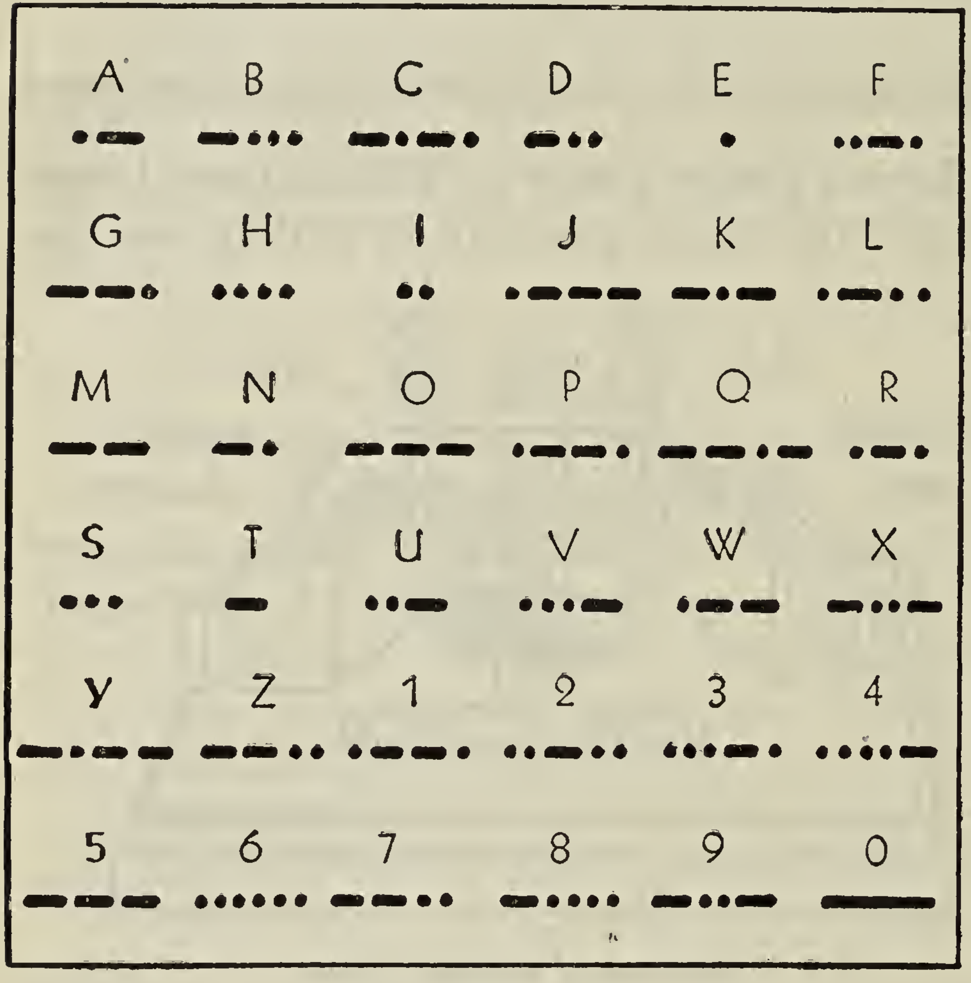
[1] After *The Book of Electricity*, by Bertha Morris Parker. By permission of Houghton Mifflin Company, publishers.



The Morse code

Obviously this motor, so far as doing work is concerned, would be a mere toy. Motors are powerful in proportion to the strength of the magnetic fields produced in both the armature and the field magnets. Consequently in industrial practice both the armature and the stationary magnets are electromagnets. By enlarging the size of the armature and the field magnets and also by increasing both the number of the armature coils and the field poles within practical limits, it is evident that motors of almost any desired power may be constructed.

Without the electric motor the wide application of electric power to the needs of everyday life would have been quite impossible. Motors are compact machines and, in factories, may be attached directly to the appliances which they are to operate. This does away with the belts, chains, and shafts necessary to steam-driven machinery. Naturally this eliminates much of the danger to workmen.

This adaptability also makes it possible to use motors as the driving device on moving machines, such as powerful electric locomotives, streetcars, and subway trains. Mine hoists are operated by them, and passenger elevators in tall buildings are raised and lowered by this noiseless and convenient method. Moreover, motors require little care, are ready to go at a moment's notice, and are controlled by a convenient switch. It is these considerations, too, that have made possible all the laborsaving devices of the home, such as electric sweepers, washers, mixers, churns, and refrigerators. Perhaps no one has benefited more through these agencies than the mother and wife who must care for her own home.

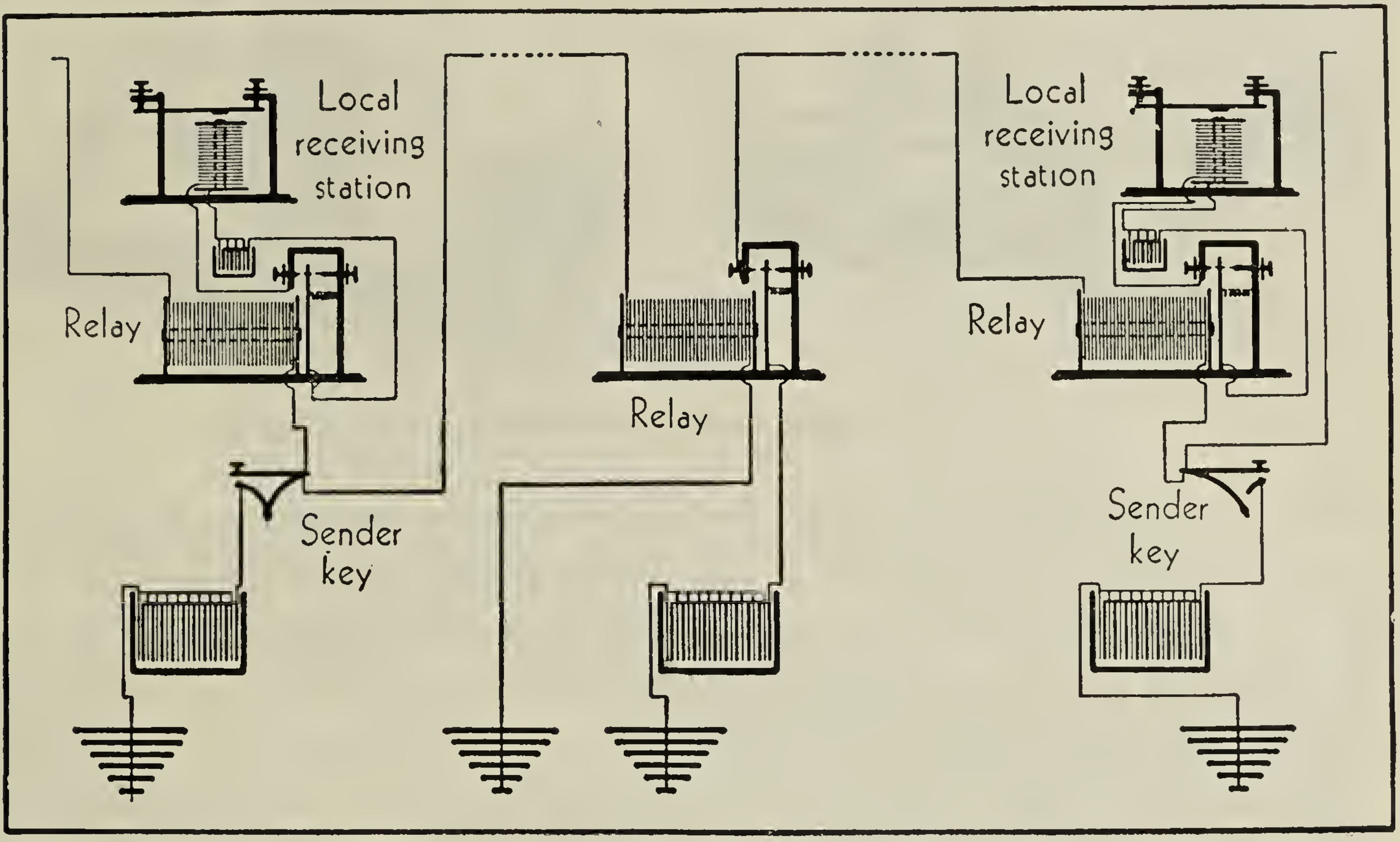
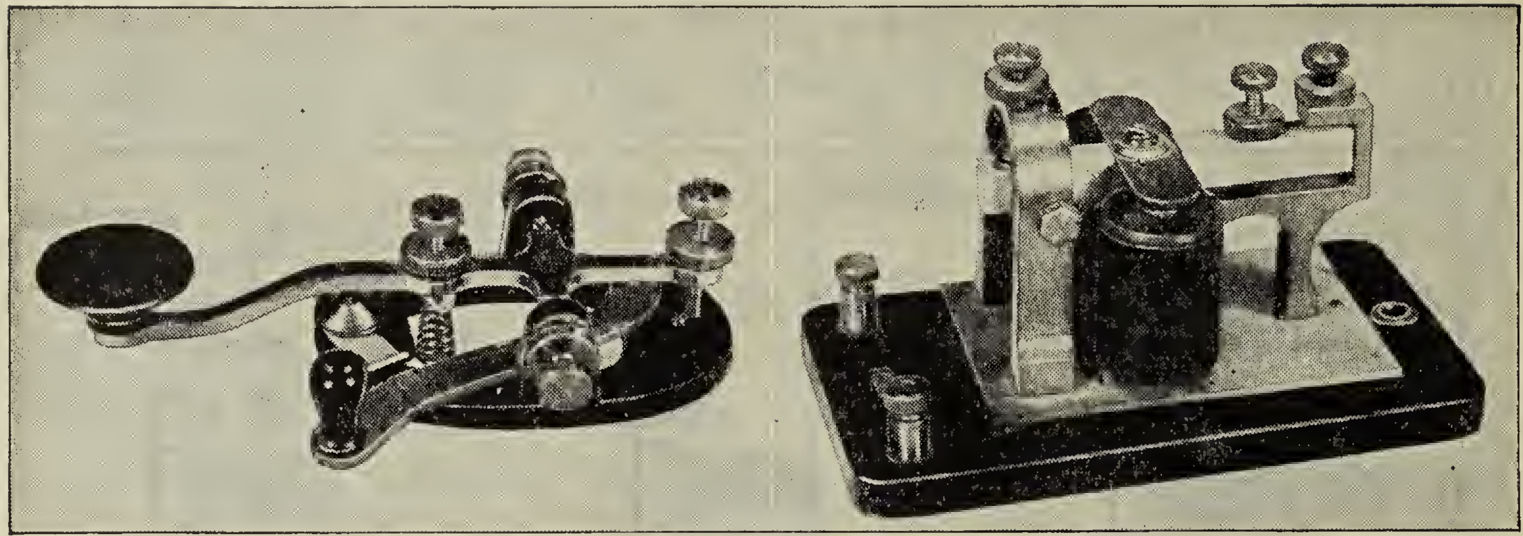


Diagram of a telegraph system with relays

Electricity Has Made Possible Rapid Communication. Samuel Morse in 1832 was returning from a trip to Europe. Previously he had been both a painter and a sculptor and was returning to America for the purpose of carrying out some special artistic plans which he had in mind. On the return trip he formed the acquaintance of a certain Dr. Jackson, and the two fell to talking about the wonders of the electromagnet, which had just been invented and which Jackson had seen exhibited at Paris.

During the conversation Morse was struck with an idea—that of utilizing the electromagnet to accomplish rapid long-distance communication. So fascinated did he become that he immediately set about an attempt to develop his new theory into a practical apparatus. As he left the boat, he remarked to the captain, "Should you hear of the electric telegraph one of these days as the



Telegraph key and sounder

wonder of the world, remember that the discovery was made on board the good ship *Sully*." Forsaking his art, Morse plunged into his inventive endeavors. Five years later he filed a patent for his first telegraph. After seven more years of grueling poverty, effort, and discouragement, he finally sent a message from the Supreme Court chamber at Washington, D.C., to Baltimore. This message, "What hath God wrought?" has become famous and marks the beginning of long-distance electrical communication in the United States.

Morse's telegraph, though crude as compared with the finished instruments of today, worked on a relatively simple electromagnetic principle. The underlying idea was that by making and breaking an electric circuit at one end of the line by means of an instrument called a key, an electromagnet could be made to respond in a similar manner at the opposite end of the line. The electromagnet at first worked a pen which made a series of dots and dashes on a moving strip of paper; hence the name *telegraph* (Greek *tēle* + *graphein*, "to write far away"). If the line were long, it was evident that a battery of very high potential would have to be used at the sending station to provide enough current to carry through to the receiving electromagnet at the far end of the line. To obviate this difficulty Morse provided relays at suitable distances to increase the current (see figure on page 353). These devices are simply local batteries opened and closed by an electromagnet in response to the sender's key. The additional current from the local relay battery was in this way sent on through the line. It is obvious that by using enough relays a message might be sent almost any distance. Later a sounder was substituted instead of the pen and moving strip of paper, and a person could receive the message directly by ear.

Morse, both wealthy and renowned, died in 1872. Before his death the same principle had been applied to the marine cable, and in point of time but a fraction of a second separated America from Europe.

A Western Union teleprinter

Today the telegraph has been supplanted in many respects by the telephone and the wireless. Nevertheless it is still a very important medium of communication, particularly in newspaper work. Subsequent patents have enabled a reporter at one end of a line to reproduce his message on an electrically controlled teletypewriter. This machine is operated just as a typewriter is and reproduces the letters, words, and sentences at the receiving end of the line through electric impulses produced in the mechanism of a similar machine at the sending end of the line. In the teletypewriter the instrument of telegraphy has again become a real "tele-graph." Teletypewriters are now used extensively in all kinds of reportorial work and commercial communication.

In teletypewriting, telephone wires may be used also. This plan enables a single sender to transmit his message through telephone centrals to an almost indefinite number of receiving stations.

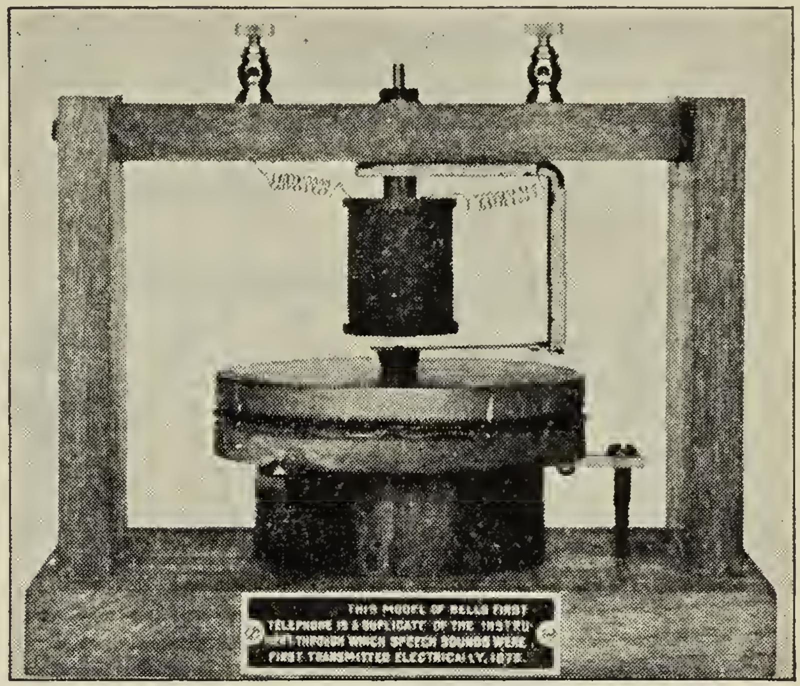
Alexander Graham Bell Invents the Telephone. Alexander Graham Bell was a teacher of the deaf and dumb. Being of a curious and inventive turn of mind, he had become interested in electrical communication. By an ingenious experiment he ascertained that a person's eardrum vibrates in response to sound waves. He took a deaf man, who consented to assist him, and inserted a straw into his ear in such a manner that one end of the straw rested on the eardrum while the outer end was held in contact with a piece of smoked glass. Bell then shouted into the deaf man's ear, causing the drum to vibrate and to record its vibrations on the smoked-glass surface. This result impressed Bell greatly, and he inquired: "Why should not a vibrating iron disk set an iron rod or an electrified wire into vibration? If I can make a deaf-mute talk, I can make iron talk!"

Bell gave up his teaching post and, with the exception of some private lessons, spent most of his time experimenting in an attempt to perfect a device that would transmit music by telegraph. One day he was working with an assistant by the name of Watson, who was at the opposite end of their experimental telegraph line in another room. The make-and-break points of the transmitter spring had fused together so that the current through the spring was continuous. The spring was set to vibrate over an electromagnet. Watson plucked at the spring in an attempt to loosen it. Instantly the crude receiver in Bell's room emitted a faint reproduction of the spring's sound at the opposite end of the line. Immediately Bell rushed in shouting to Watson: "What did you do then? Don't change anything. Let me see." Examining the spring, they found what had happened. The fused spring as it vibrated had varied the current passing through the line, and Bell's receiver had faintly reproduced the original sound. He saw at once that if his imperfect device had been able to transmit the sound of a vibrating spring, it might also, when refined and improved, faithfully reproduce the human voice.

He and Watson now abandoned all work on the musical telegraph and devoted their efforts to the telephone (Greek *tēle*, "far away" + *phonein*, "to speak"). For forty long weeks, beset by poverty and subject to ridicule, they toiled away. Finally, on March 10, 1876, their first successful attempt to carry the human voice over a current-bearing wire was achieved. On that historic day a wire had been strung down two flights of stairs from the attic to the ground floor of the house in Boston where they were working. Bell could not hear Watson, although he was shouting into the telephone as loudly as he could. But Watson could hear Bell and recognized the words "Mr. Watson, come here. I want you." These were the first distinguishable words to be sent by telephone—a rather commonplace utterance by which to introduce an invention of such importance to the world. As Watson has said, "Perhaps if Mr. Bell had realized that he was about to make history, he would have been prepared with a more high-sounding and interesting sentence."

Accustomed as we are today to all forms of electrical communication, it is difficult for us to picture the emotional effect of first hearing the human voice reproduced with accuracy over the telephone. The Philadelphia Centennial

Exposition was held in 1876, the very year of Bell's success. Naturally this new wonder, the telephone, formed one of the most interesting exhibits. Dom Pedro, the emperor of Brazil, was a guest at the fair. He had never seen a telephone and was apparently wholly uninformed regarding it. The official party conducting him about the exposition arranged that his first experience with the telephone should be a surprise. He was asked to place the receiver to his ear and someone by prearrangement spoke through the transmitter at the opposite end of the line, which was but a few hundred feet long. Dom Pedro, on hearing the human voice plainly, removed the receiver from his ear, looked at it an instant in astonishment, and then exclaimed to his hosts, "My God! It talks!"

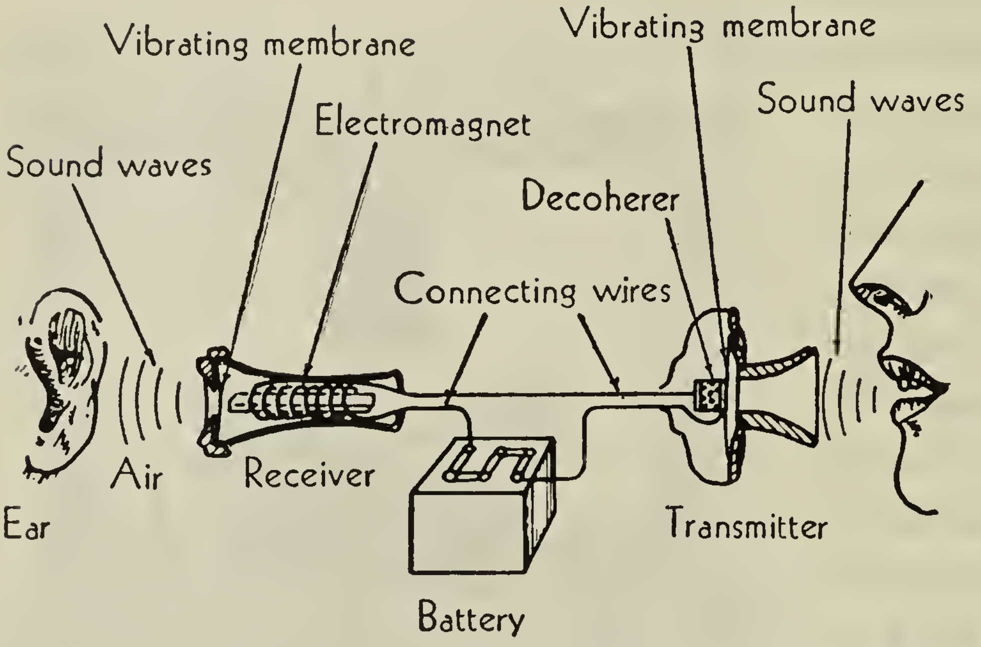

THIS MODEL OF BELLS FIRST
TELEPHONE IS A DUPLICATE OF THE INSTRU-
MENT THROUGH WHICH SPEECH SOUNDS WERE
FIRST TRANSMITTED ELECTRICALLY, 1875.

American Telephone and Telegraph Company

Bell's first telephone

Bell's telephone was a rough device compared with the telephone of today. His transmitter and receiver were essentially the same. The diaphragm of the transmitter was made of goldbeaters skin (a membrane prepared from ox gut) attached at the center to a delicate permanent magnetic bar called the armature, the latter being pivoted to work as a lever. The poles of the electromagnet connected with the battery and the transmitting line were placed close behind the armature. As the speaker spoke into the horn, the air waves caused the diaphragm to vibrate, which in turn gently moved the armature back and forth in a corresponding manner. This movement of the permanent magnetic bar induced on the magnetic coil a secondary current which was modulated in exact conformity to the original vibrations of the transmitting diaphragm and passed out over the line to another diaphragm in the receiver. Since the "speaking" current was one induced by a small permanent magnet, it can be readily seen that its power of transmission would be comparatively weak and ineffective.

Edison, with his inventive genius, became interested in the telephone, and in 1877 patented a carbon transmitter. This transmitter eliminated the induced current altogether and was so constructed that the vibrations of the diaphragm produced a corresponding fluctuation in the battery current traversing the line. Essentially the transmitter consists of two polished carbon disks, insulated from the box in which they are set and also insulated from each other except through a narrow gap filled with fine carbon granules. The front disk is attached by a slender post to the center of the aluminum diaphragm and moves in and out freely in response to the vibrations of the latter. This disk is also connected with one of the line terminals by means of a delicate spring. The back disk is stationary and is connected with the other line terminal. As the diaphragm vibrates in response to the speaker's voice, it varies the pressure upon the carbon particles in a corresponding manner. When these particles are compressed, they conduct a current readily; but when the tension is relieved, the flow of current is cut down proportionately because of the looser connection, and hence greater resistance, formed between the particles themselves and between them and the faces of the disks. The current passing from the receiver out through the line, then, is varied in intensity and modulated in exact conformity to the vibrations of the diaphragm itself.



American Telephone and Telegraph Company

Diagram of a telephone transmitter and receiver

The receiver, as now perfected, consists of a permanent horseshoe magnet held in place by a hard-rubber cylinder which is expanded at the outer end to receive the thin soft-iron disk. The disk itself is fastened rigidly around the circumference by a gutta-percha screw cap perforated at the center. The poles of the electromagnet, situated just behind the disk, are wrapped with many turns of fine wire in such a manner as to form a continuous circuit from one binding post to the other. As the modulated incoming current passes through the coils, its fluctuating intensity varies the magnetic field encompassing the disk. The vibrations thus produced in the disk are conveyed to the ear as sound waves and, to a surprising degree, reproduce the quality, pitch, and volume of the speaker's voice at the other end of the line.

To send messages over long distances requires a voltage higher than the original telephones supplied directly from voltaic cells could produce. Morse, in sending his first telegraph message from Washington, D.C., to Baltimore, is said to have used a battery of one hundred cells to furnish the power. Edison surmounted this difficulty in the telephone by removing the transmitters from the line circuit and connecting them to it through step-up transformers. This greatly increased the efficiency of the telephone and facilitated its much wider use for both private and commercial purposes.

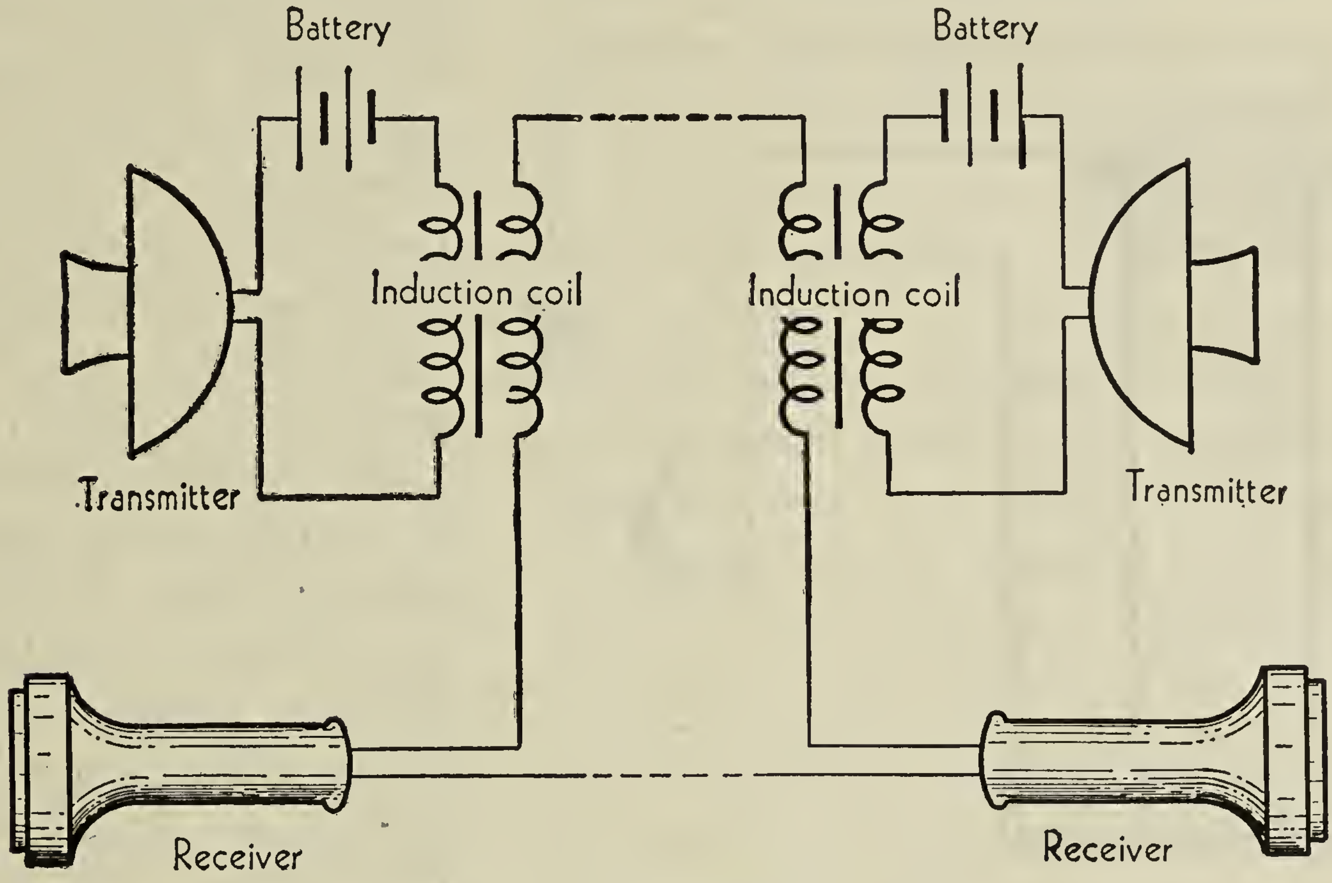


Diagram of the Edison telephone circuit

The one invention, however, which more than any other made the telephone an established success was the Edison carbon-plate transmitter. For this patent Mr. Edison received $100,000. In 1915 the first transcontinental telephone was opened between New York and San Francisco. In opening this line Bell and Watson again took the spotlight, just as they had when the first trial conversation was carried on by them between the attic and the ground floor of the Boston house thirty-nine years before. The same message was used. Bell in New York said to Watson in San Francisco, "Mr. Watson, come here. I want you." But instead of hastening up a couple of flights of stairs and appearing in a moment, Watson responded, "It would take me a week now." Telephone lines today unite the principal cities of all foreign countries, and many of them cross international boundaries. All of which shows to what extent modern life has been influenced by the persistent efforts of two men to talk over a wire.

The Electric Storage Battery Is Widely Used with Modern Appliances. Electricity may be conducted almost anywhere on transmission lines. These lines, however, are expensive to build and, because of this, cannot be run profitably into remote and sparsely settled districts. Moreover, electricity is used in different ways to operate many mobile conveniences successfully. Among these are the automobile, airplane, and the submarine, which do not follow a constructed track and which, for this reason, cannot be connected with a power line. To meet this need, electric storage batteries have been designed. These batteries are built much like a voltaic cell except that lead plates may be used instead of copper and zinc plates. The purpose of the two is entirely different, however. The voltaic cell is designed to produce an electric current, whereas a storage cell is made to store chemical energy which may later be released as a current.

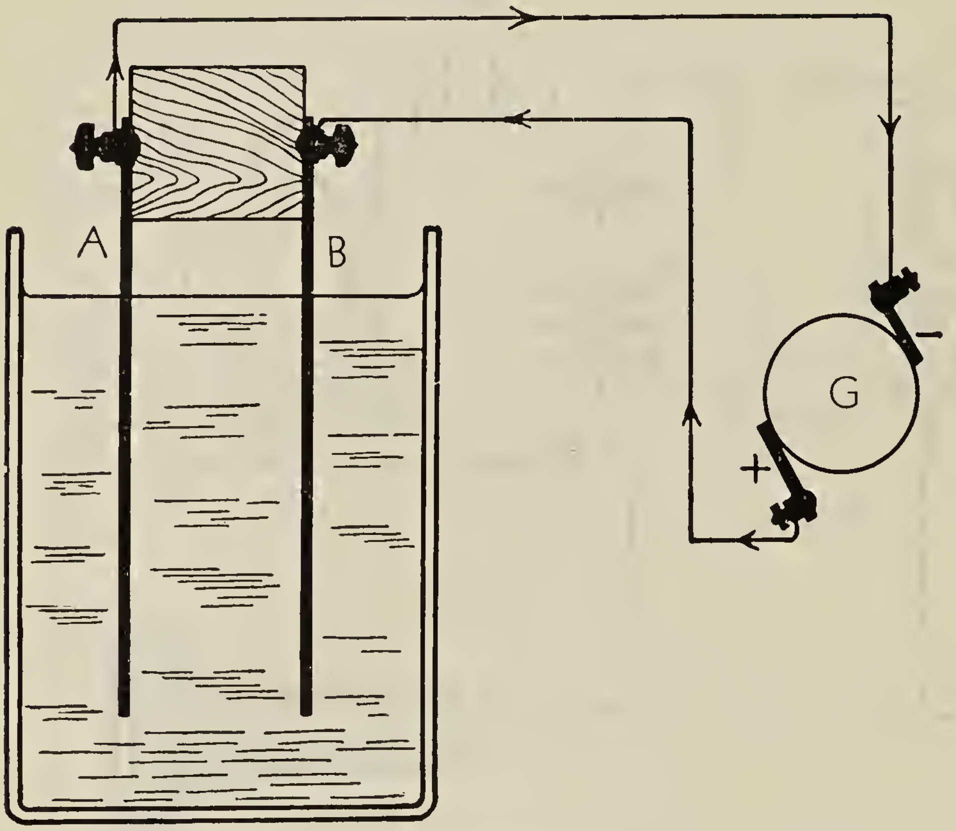


Diagram of a storage battery

A and *B*, lead plates; *G*, generator

Although storage batteries of various kinds and of different degrees of complexity are built, the principle upon which they operate may be explained by reference to a rather simple storage cell (see the illustration above). This apparatus consists of a battery jar containing a dilute solution of sulfuric acid as the electrolyte. Two lead plates, *A* and *B*, insulated from each other, are lowered into the solution in the manner shown and are connected with an external direct-current generator, *G*. The charging, by which energy in the potential chemical form is stored in the cell, and the discharging, by which electrical energy is released from the cell to do work, are the results of chemical reactions. While being charged plate *B* takes on a brown color, owing to the formation of lead dioxide on its surface. This plate is the anode of the charged cell. Plate *A* retains the gray color of pure lead and becomes the cathode.

If the cell is now disconnected from the charging circuit and the plates are connected, by placing a galvanometer in the circuit a current will be seen to flow in the opposite direction—that is, from plate *B* to plate *A*. The cell is then said to be discharging, or furnishing a current that may be used to do work. As the discharge continues, the sulfuric acid reacts on the lead dioxide to form lead sulfate ($PbSO_4$). This reaction gradually consumes the lead dioxide and the sulfuric acid and "runs down" the battery.

The concentrated sulfuric acid used to form the electrolyte in automobile batteries has a specific gravity of about 1.835. Since the specific gravity of pure water is 1.0, the density of the diluted acid is lowered as water is added. Dilution is continued until the specific gravity of the liquid ranges from 1.275 to 1.300. At this point the battery, provided the plates are in proper condition, is considered to be fully charged.

As discharge takes place and the acid from the electrolyte is combined with the lead dioxide, it is obvious that the current furnished by the cell will gradually become weaker. Automobiles are provided with chargers to keep up the charge of the battery; but as the battery ages, or if a short circuit should develop, its electrical strength gradually falls. This result is indicated by a commensurate fall in the specific gravity of the liquid. When a specific gravity of from about 1.130 to 1.180 is reached, the battery is completely discharged and must be recharged if it is to be used. Filling-station attendants can determine the strength of a car battery at any time by the use of the hydrometer. If a battery has become run down so that it requires recharging, this may be done by connecting it again with a source of direct current, as at first.

Doubtless the most extensive use of the storage battery occurs in automobiles. A self-starter would be impossible without this source of energy, as would also an electric-lighting system when the car is not running. Modern cars take the current for all purposes (lighting, starting, and horn signals) from a storage battery, the charged condition of which is maintained by a generator. Formerly, if the motor was started often for the distance traveled, as in city driving, the battery ran down and had to be recharged more frequently than when long trips were taken. Modern cars have a voltage regulator which enables the generator to charge more heavily as the strength of the battery falls. When an exceptionally heavy load is thrown on the battery, it discharges at a much more rapid rate. It is for this reason that trying to start the engine of the car on a very cold morning, when it will not turn over readily, exhausts the battery.

Storage batteries have made radio sets possible in all districts of the country remote from electric lines. Many a family on the Western plains, far removed from the city, and many families in mountain homes isolated from the rest of the world, may enjoy a symphony today just as readily as the metropolitan dweller. Without the storage battery to supply the receiving set with electrical energy this would be impossible. Private lighting plants, automatic electrical controls, emergency lighting in subways, and the motive power for submarines when submerged, as well as dozens of other uses, all depend on the storage battery for their successful operation.

Questions for Study

1. To what extent is the electric motor used in modern household appliances?
2. What are the important scientific principles involved in the construction and in the operation of the electric motor?
3. How has the use of electricity made the daily lives of people on farms and in villages and cities today different from the lives of those who lived a hundred years ago?
4. Why was the long-distance telegraph impracticable until electricity produced by a relay battery was available?
5. How is it possible for man to transmit speech or music over wires?
6. Why are automobile batteries much more likely to become exhausted in cold weather than in hot weather?
7. Why do physicists object to describing the electric storage battery as a device which stores electricity?
8. How has the perfecting of modern means of electrical communication affected man's attitudes toward the world in which he lives?
9. How would you explain the action of the hydrometer used to test the strength of an automobile battery and of an antifreeze solution in a radiator?

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CHAPTER TWENTY-ONE

Energy May Take the Form of Radiations

Man Has Advanced Different Hypotheses to Explain the Nature of Light. The early Greeks had peculiar conceptions concerning the nature of light and vision. Some of them believed in the doctrine of ocular beams, which held that the eye emitted minute particles of some kind. When these particles met something which was emanated by the object, sight resulted. Other Greeks believed that sight resulted when particles projected from the object entered the pupil of the eye. Man's conception of light appears to have advanced little beyond this particulate idea until the scientific age was ushered in at the beginning of the seventeenth century.

In 1678 Christian Huygens, a Dutchman and a native of the Hague, laid down the proposition that physical light is a series of waves emitted by a luminous body and propagated through an all-pervading ether. This same idea had been proposed earlier by an Englishman, but Huygens developed it into a well-rounded theory which caught the ear of European scientists when he announced it. He explained the reflection and refraction of light rays on the basis of undulatory waves, much as we do today.

Isaac Newton, a young contemporary of Huygens, a few years later advanced a different theory as to the cause of light and vision. Newton observed that light does not bend around a corner, as sound waves do. A person can hear the report of a gun fired on the other side of some high object that obstructs the view; but he cannot see the flame of a candle on the other side of that same object even at night. The darkness may be relieved only by the comparatively few candle rays that are reflected from surrounding surfaces. This, said Newton, shows that light is not a series of waves, else it would bend round behind the object, just as sound waves do. Whereupon he evolved what is known as the corpuscular theory of light. In effect, this theory holds that luminous bodies emit streams of minute moving corpuscles that travel in straight lines. Vision results, so Newton believed, from the impact of these tiny particles on the retina of the eye.

Today we know that Newton's idea of material corpuscles was erroneous. Light is not a ponderable substance. It is a form of radiant energy. Yet the power of a master to influence public opinion by the sheer weight of his authority, even though erroneous in his views, has scarcely ever been better demonstrated than in the case of Newton's theory as to the nature of light.

His view almost completely eclipsed that of Huygens and for a hundred years or more pushed the latter into the background.

This example, as well as many others that might be taken from the pages of scientific history, cautions us that what men say, when they are speaking in the realm of theory, should not be accepted as truth merely because they say it. Due respect should always be accorded the views of investigators in their own fields. Such views are much more likely to be correct than the views of men who are not specialists in these fields. But the theories of even masters should always be verified experimentally before they are accepted as truth. Verification and proof have come to be the very pillars which support the edifice of scientific knowledge. We now know that Huygens, though perhaps not entirely correct in his ideas, was much more so than Newton.

Thomas Young Revives the Wave Theory of Light. The particulate, or corpuscular, theory of light was strongly challenged by Thomas Young, a young English physician. In 1801 he read a paper before a learned scientific society in which he revived the wave theory of light. He found that when light waves are manipulated so as to throw two combining waves into the same phase,—the crest of one wave upon the crest of the other wave,—they are "exactly in step" and amplify each other; then the particular point where they fall is more brightly illuminated than it would be by either wave alone. When the waves fall in directly "opposite step,"—the crest of one wave upon the trough of the other wave,—they destroy the effect of each other so that at that particular point there is no light at all, but a dark area. As a result, when Young experimented with interfering light beams, he got a series of alternating light and dark rings. From this he reasoned that light must take the form of waves instead of corpuscles; otherwise it would be impossible to account for the alternate light and dark areas which he had produced.

Young's paper precipitated a great controversy between those who joined with him in his views and those who took up the gauntlet in favor of the corpuscles. One of his antagonists, a bombastic Lord Brougham, denounced the principle of interference as "absurd" and "illogical," although every high-school student of physics today knows it to be a fact. He closed his review of Young's paper in these caustic words:

> We now dismiss, for the present, the feeble lucubrations of this author in which we have searched without success for some trace of learning, acuteness, and ingenuity, that might compensate his evident deficiency in the powers of solid thinking, calm and patient investigation, and successful development of the laws of nature by steady and modest observation of her operations.[1]

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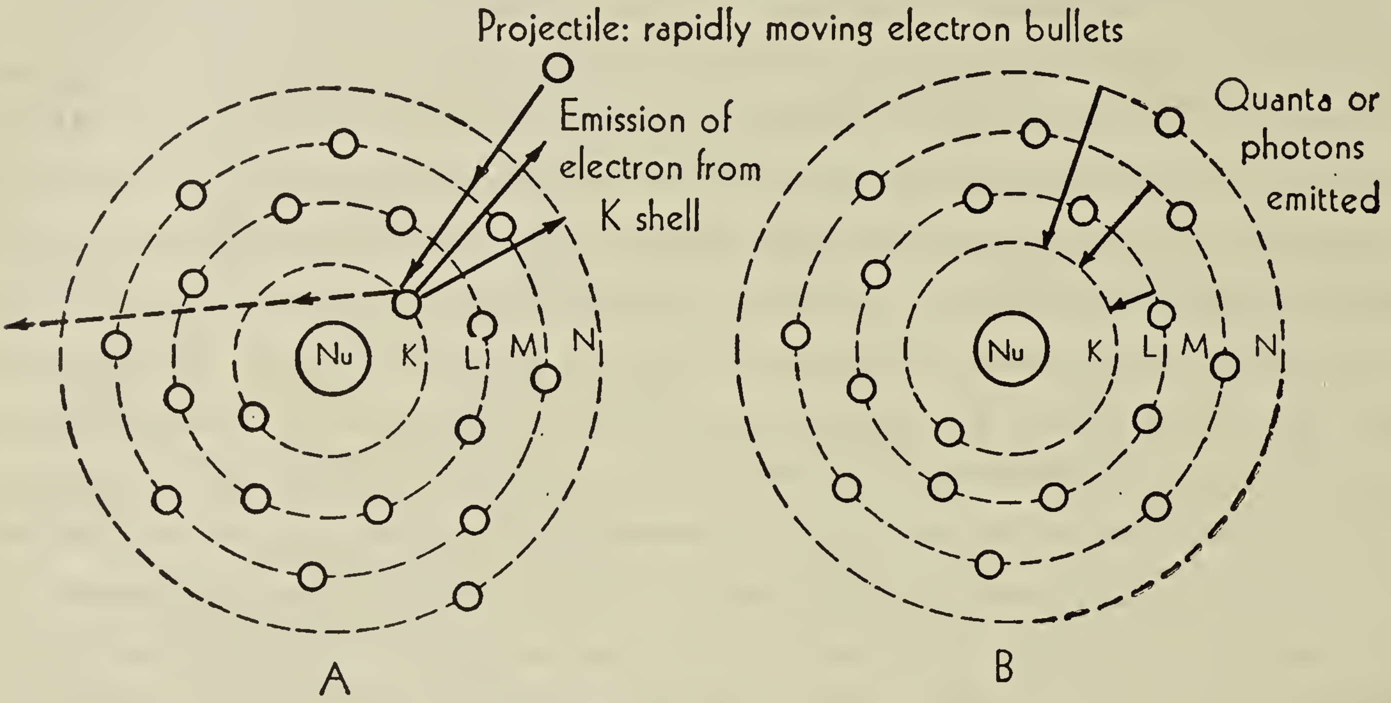
[1] *Edinburgh Review*, Vol. 5 (1805), p. 103.

Needless to say, the vituperative Lord Brougham has long been forgotten in scientific circles, but the name of Thomas Young is honored as the discoverer of light interference and the reviver of the undulatory theory of light.

After the revival of the wave theory by Young, it again grew in favor to the point of completely dethroning the Newtonian corpuscular theory. However, the position of the unqualified undulatory theory has never been a secure one. In many respects light does act like waves. It may be reflected, refracted, polarized (made to vibrate in one plane only), and made to interfere precisely as it would behave if it were a series of waves. On the other hand, its action when, for instance, it affects a photoelectric cell appears to be much more in harmony with corpuscular behavior. These light corpuscles, to be sure, are not to be thought of as *material* particles in the sense that some of the older corpuscular theories viewed them. Rather they appear as discrete bundles of energy which behave in some respects as if they were separate particles. But before these later views concerning the nature of radiant energy can be appreciated, it will be necessary to consider first how these corpuscles of energy are believed to be expelled from an emitting body.

Radiant Energy Is Believed to Be Emitted as Photons. Formerly it was held by physicists that, although matter was discontinuous, energy, such as light, was not. One might divide and subdivide an element down to its very atoms. He might go even farther, if he knew how, and separate the atom into its constituent protons, neutrons, and electrons. But when he had reached this point, he was at the end of his dividing power. He could go no farther. These particles represent the extreme limits of material divisibility. On the other hand, visible light, X rays, and other forms of radiant energy were conceived to be sent out by the emitting body in a continuous, uninterrupted flow. As Heyl says, the difference between the views as to the nature of matter and energy may be illustrated by two sacks of marbles. If a suitable hole be made at the bottom of one sack, all the marbles can be made to drop out, leaving the bag empty. But they do not emerge continuously. They come out by jumps, one marble at a time. On the other hand, if all the marbles in the second bag be ground to fine powder, and an appropriate opening be made at the bottom of the sack, the marble dust will issue in a fine, steady stream until the bag is emptied.

In recent years, however, especially since 1900, there has been a decided change in men's ideas as to the manner in which radiant energy of all kinds is emitted. It is now believed that, instead of being expelled in an unbroken stream, radiant energy is discharged in discontinuous bundles, or "shots," much as single bullets come in rapid succession from a machine gun. There are so many of them and they come in such quick succession that they give the impression of a continuous flow. The man who first advanced this idea was a German professor by the name of Max Planck. He called the quantity of energy in one of these "packets" a *quantum*. The unit itself is called a *photon*.

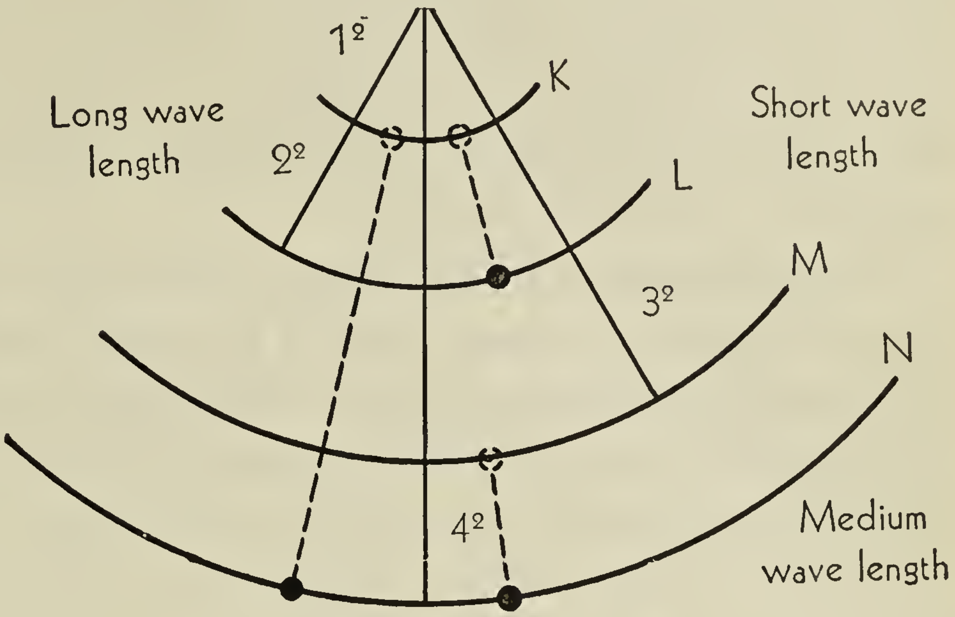

Projectile: rapidly moving electron bullets
Emission of electron from K shell
Nu
K
L
M
N
Quanta or photons emitted
A
B

Bombardment of an atom

When an atom of a heavy substance (*A*) is bombarded by a rapidly moving electron projectile which has sufficient energy to penetrate to the inner K shell, an electron may be displaced from the K shell. Since the L and M shells are already complete, the dislodged electron must move to the N shell or to the outside. This leaves a vacancy in the K shell. (*B*), the vacancy in the K shell may now be filled by an electron moving from the L, M, or N shell, giving out a definite quantity of energy (quantum) as it moves inward

How Quanta Are Believed to Be Produced. If radiant energy is emitted from a body in shots instead of a steady stream, one's curiosity naturally leads him to ask how these shots are fired. In other words, how are these bundles of energy expelled and sent out on their course through space?

There are still many perplexing aspects of quanta and photons, but evidence, from X rays especially, accumulates which indicates that the emission of photons can best be explained on the basis of Bohr's atom. This atom, it will be recalled, assumes a sort of planetary arrangement, with the heavy nucleus at the center and the electrons revolving in orbits about the nucleus. Planck's conception assumes that, although there may be many different orbits, or energy levels, about the nucleus of an atom in which the electrons may revolve, nevertheless the paths which these electrons follow always maintain their fixed radial position with reference to the nucleus. The diameters of these orbits, proceeding from the center outward, run as the squares of the numbers 1, 2, 3, 4, 5, and so on. In these orbits the electrons must travel, and cannot occupy the space between orbits. The speed at which the electron moves within limits is definite and invariable for any single orbit. The electron cannot go either faster or slower while in this particular path. The comparative velocities maintained in successive orbits, however, are different, increasing constantly from the outer to the inner orbits, just as the speed of the planets in their revolution about the sun is found to be faster in each case as one proceeds from Pluto to the innermost planet, Mercury. Beginning at the outside the speeds of the electrons are proportional to the numbers 2, 4, 6, 8, and on in this relation.



Electron jump

An electron jump from shell L to shell K produces shorter wave lengths than a jump from N to M, while a jump from N to K produces a still longer wave length. The distance between the shells is indicated by the squares of 1, 2, 3, and 4

This setting as to orbital arrangement and relative electron speed just given prepares the stage for the next scene, in which we are to see how the quanta are conceived to be "kicked" out into space. It is conceived that though electrons cannot occupy the space between orbits, they can jump from one orbit to another under the influence of some kind of external stimulus. As the jump is made from an *outer to an inner* orbit, a "kick" of definite magnitude is emitted which is propagated out through space as a quantum. To be more concrete, when a stove is heated to redness, the electrons are first displaced from their orbits by the application of heat. They then bound back in again; and it is this inward bound of myriads of electrons, each either from outside the atom or from the orbit now occupied to another nearer the nucleus, that emits energy and in so doing produces the visible photons which we recognize as light.

Since electrical forces, like gravitation, vary inversely as the square of the distance from the center of attraction, it becomes evident that electron jumps between inner orbits will be made more quickly than jumps of corresponding magnitude farther out from the nucleus. Consequently photons emitted by a jump from the L to the K shell, for example, will have a shorter wave length than those emitted by a jump from the N to the M shell. Electrons may also bound across two or more orbits on their way in toward the K shell. This again gives waves of different length.

The atom of many kinds of elements is conceived to have many orbits surrounding its nucleus in which electrons may travel and from each of which an electron may spring to any one of the others. Different elements have different numbers of orbits, which in some cases, as in iron, may mount up into the hundreds. In this way it is possible for a single atom of an element to emit a long series of wave lengths. Particularly is this true if the atom is heavy and complex.

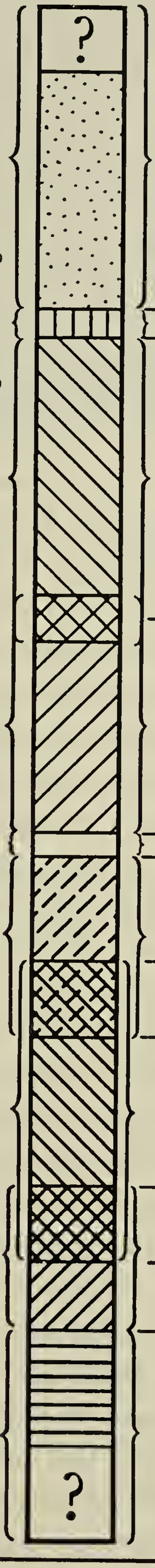
Since the electrons emit energy in the form of photons when they jump from an outer to an inner orbit, it is evident that to reverse the direction of the electron jump must require the application of energy. In other words, work must be done upon the electrons to force them from one orbital position to orbital positions farther out from the atomic nucleus. The energy applied to do this may take different forms, such as heat, violent molecular collisions, as when a streak of lightning pierces the atmosphere, electrical forces, or photons themselves.

Electron shifts are believed to produce the phenomenon of fluorescence observed in certain minerals. These minerals are made to glow by subjection to ultraviolet light. The explanation offered is that the short, powerful, ultraviolet radiations force electrons of the mineral atoms outward from the nuclear center. But now, since there are vacancies left in the inner orbits, either the displaced electrons themselves or other electrons will immediately bound inward to complete again the atomic complement. These subsequent inward jumps cause photons or waves, if we take Huygens's view, of different lengths to be emitted, which produce a fascinating array of colors. In visible light it is this difference in wave length that gives the different spectral colors, ranging from red to violet. A combination of many of them, such as is afforded by sunlight, produces the sensation of white light.

Quanta Have Definite Properties. Though quanta are all considered to be definite "shots" of energy, no one knows exactly what form they take. We remember that Huygens thought light existed as waves and that Newton believed it to be corpuscular bodies. The material-particle idea of Newton, as we have found, has been abandoned. Physicists do hold quanta to be definite units of energy, but whether they go through space as "packets" or as waves is not known. Generally they exhibit the characteristics of waves, but sometimes they appear to act more like energy in corpuscular form.

Quanta also differ in the energy they contain. The longer the wave produced, the less energy it possesses; the shorter it is, the more energy it has. The waves producing violet light have almost twice as much energy as those producing red light. These waves are all alike, however, in at least one respect,

The Complete Electric Wave Spectrum



Kind of Waves	Octaves	Approximate Length	Usual Method of Detection
		Infinity	
Long electric	14(?)		Electrical resonance Electro-magnetic induction Oscillographs
Radio			
Broadcasting band	1.5	545.1 meters 199.5 meters	Electrical resonance in tuned circuits
Radio			
Short electric	13		Electrical resonance
		$\frac{3}{100}$ cm	
Infrared (Heat)	10		Heating effect
		$\frac{78}{1\,000\,000}$ cm	Chemical effect
Light	1		
		$\frac{39}{1\,000\,000}$ cm	Eye
Ultraviolet chemical	8.6		Fluorescence
		$\frac{1}{1\,000\,000}$ cm	Chemical effect
		$\frac{1}{10\,000\,000}$ cm	Chemical effect Ionization
X-ray	14.3		
		$\frac{1}{100\,000\,000}$ cm	Fluorescence
Gamma rays	6.6		
		$\frac{5}{10\,000\,000\,000}$ cm	Chemical effect Ionization
		$\frac{1}{10\,000\,000\,000}$ cm	Fluorescence
Cosmic rays	?	?	By penetrating and ionizing power

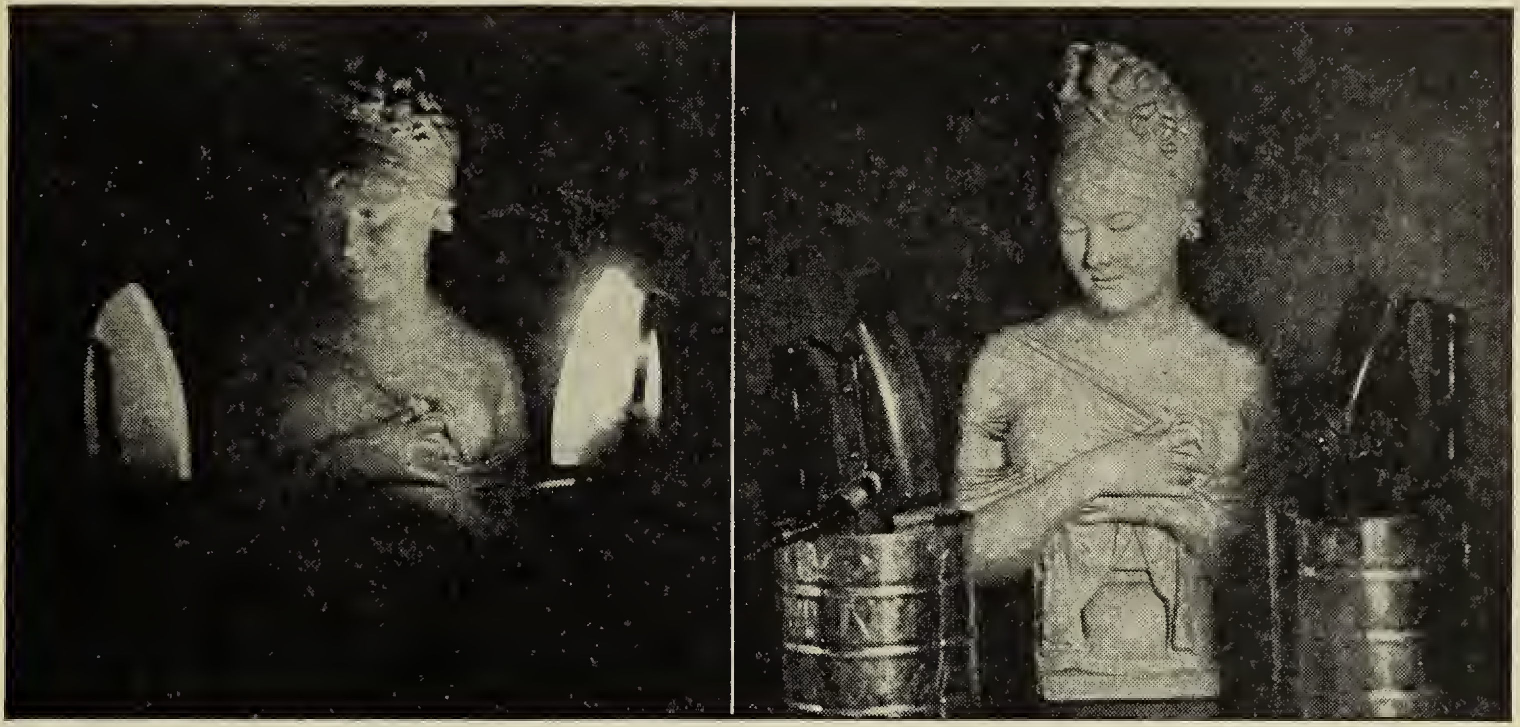
and that is the speed at which they travel. Regardless of whether they are a mile long or a billionth of an inch long, they travel through empty space at the same velocity, which is approximately 186,000 miles per second.

Radiant Energy Manifests Itself through a Wide Range of Wave Lengths. The ancients believed light, like gravity, to be instantaneous in its action—that is, that it did not have to travel from one body to another to exist between them, but rather, the instant a luminous body came into existence, the light was there between it and other objects.

The discovery that light is something which travels between two bodies and consumes time in its passage is believed to have been made by Olaus Römer, a Dane, in 1675. Römer was studying the satellites of Jupiter, which revolve round the planet regularly. He noted that when the earth was on the farther side of its orbit from Jupiter, the "moons" seemed to lag behind the calculated time that they should have entered the shadow and be cut off from sight. He was puzzled about the matter; but finally, after much study, he made the bold and novel assertion that light is not infinite in its speed but finite, and that the discrepancy between the observed time and the calculated time in the eclipse of Jupiter's moons by the planet was due to the time it took light to traverse the diameter of the earth's orbit. Although much criticized from many quarters at first, Römer's views are now accepted, and the exact time of the discrepancy is set at a little over sixteen minutes. This makes the velocity of light about 186,000 miles a second.

Careful computation by physicists shows that radiant energy has a very wide range of wave length and that the visible light rays cover but a small portion of this wave-length range. The keyboard of a piano represents about seven or eight octaves of pitch. In visible light the length of the violet light wave is just about one half that of the red light wave. Or, to put it in other words, the vibration rate which emits the violet wave is approximately twice that which emits the red wave. Now, if one begins with the longest waves and lets the length of these successive steps, in which the vibration rate is doubled in each case, represent octaves of radiant energy, then a radiant energy "keyboard" sufficiently long to represent all the known different wave lengths would have to be almost sixty octaves.

The longest waves used by very low-frequency radio stations are perhaps from fifteen to twenty miles long. Above these there are radio waves of shorter frequency employed by commercial stations, but all the waves in this range have not yet been produced. Next come the long infrared heat waves, easily detected by focusing them on the bulb of a sensitive thermometer, by using the thermocouple, or by employing special infrared photo-



Eastman Kodak Company

Infrared rays

A, picture taken by the infrared rays emitted by two electric irons; *B*, an ordinary picture, showing the arrangement of the objects in *A*

graphic plates. Infrared photographic plates and photoflash lights are being used by news photographers in England to overcome the difficulties encountered by "black-outs" during the second World War.

The visible light waves range from red, beginning about $\frac{31}{1,000,000}$ of an inch long, through all the other colors to violet, which ends at something like $\frac{15}{1,000,000}$ of an inch in length. The ultraviolet are detected mostly by their chemical effects, as are the X rays in special photography. The gamma rays are very similar to X rays in their effect, and we have found them to be one of the three forms of radiant emanations produced when radium disintegrates. Above these come the cosmic rays, recently discovered and believed to be the "hardest," or most penetrating, rays yet known to man. Their length varies and has not yet been definitely determined. However, they have been roughly estimated to be in the neighborhood of $\frac{1}{50,000,000,000}$ of an inch in length, and, because of this extreme shortness, will penetrate a layer of water sixty feet deep. Yet it is known that the wave lengths of this great range are all similar in character because they apparently are all capable of traversing space with facility.

At present the most mystifying radiant-energy waves are the cosmic rays. These strange rays are believed to come from outer space. This inference is based on the fact that readings taken at high elevations show a much greater intensity of these rays than readings taken at sea level. Data obtained by the use of small balloons carrying either tiny recording instruments or broadcasting devices which transmit information back to the earth, show that at elevations of approximately 15 miles the intensity of these rays is about 200 times greater than at sea level. It was largely for this reason that they became known as cosmic rays.

As has been noted, the most striking property of cosmic rays is their extreme penetrating effects. These penetrating effects, however, are for the most part not those of the original rays themselves but of secondary radiations which have been liberated from the nuclei of atoms disrupted by the original cosmic rays. At Lake Constance in the Swiss Alps the harder of these rays were found to pass through a layer of water over 900 feet deep. In Michigan observations made in an old mine revealed that the shorter cosmic rays penetrated a rocky cover 1600 feet thick.

The exact nature of cosmic rays is difficult to determine. When certain of them make a direct hit on an atmospheric atom, they disrupt it, thereby throwing out electrons, protons, and perhaps neutrons, like shrapnel from an exploding shell. It is difficult to separate the rays themselves from these secondary particles that are released. Although cosmic rays are spoken of as "rays," they seem rather to be particles, since their course is deflected to a considerable degree by the influence of the earth's magnetic poles.

The ultimate source of these extraordinary rays is still a baffling puzzle. At first they were believed to have their origin in the sun; but extensive readings taken both during the day and at night show no significant difference in intensity. Moreover, if these rays had their origin in the sun, during total solar eclipses they ought to be almost wholly cut off from the earth. Careful measurement, however, shows no detectable difference in their intensity at such times.

Another theory places the origin of cosmic rays outside the solar system but within our own galaxy. On the other hand, evidence has been accumulating which may place the origin of the rays far out in the so-called extragalactic nebulae. Still other hypotheses have been proposed. But as Blackett recently said, "Many . . . possible explanations of the origin of the rays have been given, but none put forward hitherto seems very plausible." Consequently the question of origin and many other aspects of cosmic rays will have to await the further progress of research in this fascinating field.

Radiations of Certain Wave Lengths Are Visible. From what was said about the wave length of light before we digressed to consider cosmic rays, it is obvious that visible light is insignificant in range when compared with the great range of rays that are invisible. It is as if one were to attempt to play a tune upon one octave of a huge keyboard while the keys of almost sixty other octaves, ranged along on either side, remained silent and ineffective. One is enchanted now by the play of lights, shades, and colors that he can perceive, but he wonders what sublime symphonies of light and color could be produced if his eye could but respond to the roll of the long, deep bass waves on up through the whole range to the sharp, high-pitched notes of the cosmic rays. And yet if he could, the sheer number and variety of wave lengths playing on man's comparatively feeble eye might make vision a mere jumble and confusion.

White, visible light, as most people are aware, is produced by the effect of many different ranges of radiant wave lengths striking the retina of the eye together. Newton demonstrated this when he passed a ray of sunlight through a glass prism and, by its difference in refrangibility, transformed it into the beautiful rainbow-colored spectrum. All that we know of color, tint, and shade depends upon the proportion and intensity of these wave lengths in the combination. Leave any range out, and the effect is different. Almost everyone has had the experience of purchasing a garment by artificial light, only to find that its color was disappointingly different when brought out into daylight. Why this change in color? Simply this: that the artificial light in the store did not contain all the wave lengths combined in the white light of the sun. That alone was the cause of the discrepancy in color.

Light Waves Are Affected by Different Substances in Various Ways. Many aspects of light waves and their physiological effect on the human retina are not yet fully understood. But it is believed that when waves of sunlight, for example, strike an object, they encounter different conditions and movements of electrons. In the case of a black object the visible light rays are absorbed. In this case they disappear as radiant energy and are transformed into heat by an increase in the velocity of molecular motion. Probably no substance can completely absorb *all* visible rays, but in a substance such as lampblack this condition is closely approximated. It now becomes evident why dark-colored soil and the closely adjacent air is warmer on a sunny day than a white surface of the same heat capacity. A thermometer placed at the surface of dark soil in Colorado on a clear July day showed a noon temperature of 132° F, while the air temperature stood at 104° F. For the same reason dark-colored clothing is seldom worn by people who live in the tropics or, in midsummer, by those living in a temperate climate.

If the light strikes an object whose electrons *just* under the surface are made to vibrate more forcibly but at such a rate as to produce waves of the same length as the incoming ones, then that surface becomes a reflecting one. There are perhaps no perfect reflectors. Every surface, regardless of how highly polished it is or of what material it is composed, will absorb some small fraction of the incident rays; but highly polished glass and smoothly coated mercury or aluminum surfaces closely approach the condition of a perfect reflector. The angle at which the light strikes the surface affects the percentage of the light reflected. Even a smooth dark pavement at night makes a rather troublesome reflector when the angle of incidence is sufficiently great, as every automobile-driver well knows. Water on the pavement improves its reflecting properties, as is clearly demonstrated on a rainy night. Anyone who has tried to look at the setting sun across the placid waters of a lake on a clear evening has also received a vivid demonstration of how an increase in the angle of incidence of the light increases the intensity of the light reflected.

If a substance permits the light to penetrate it freely, we say it is transparent. Probably in this case the electrons of the substance are so arranged as not to be affected in any perceptible way by the transmitted light waves. Some glass is now made so nearly perfect in this respect that when viewed from the proper angle it is almost completely invisible.

Light rays can also be scattered. If a narrow beam of white light is admitted through a small aperture into a darkened room with a dusty atmosphere, the path of the beam can be readily traced by an observer at the side. This is due to scattered rays which are deflected from the main beam to the eye of the observer by the dust particles. Owing to their scattering effect the specks of dust themselves appear not in distinct outline but as tiny, illuminated particles. This effect is very evident when a beam of light passes through a smoky or a foggy atmosphere at night.

The effect of scattered light also produces the blue color of the sky. In this case small particles, such as dust and atmospheric molecules, act as scattering agents. When the particles are small, the short (blue) wave lengths are scattered more than the long (red) ones. It is for this reason that the sky takes on its beautiful azure hue. If it were not for the scattering of light, the sky would be coal black. The same principle accounts for the characteristic redness of the rising or setting sun. In this case the light rays traverse such a deep layer of atmosphere that the blue wave lengths are scattered out, leaving the longer reddish rays to penetrate on through to the eye of the observer.

Color seems to be due to a sort of selective absorption. Take a green leaf, for example. In this case all the rays except those imparting the sensation of green are absorbed by the tissues. The green-producing waves are conceived to be "in tune" with certain of the electrons in the leaf in such a manner as to incite them to produce secondary "green waves," which strike the eye of the observer in their outward course and produce the green-color sensation.

Light Has a Photoelectric Effect. Stimulated by Hertz, who, in 1887, was the first scientist to discover that radiant waves could be produced by an electric spark, Hallwachs, another German, began a thorough study of this whole phenomenon. Among other things, he mounted a clean, carefully insulated zinc plate and directed a beam of ultraviolet light upon it. He was surprised to find that under the stimulus of the ultraviolet light the plate gradually took on a positive charge, which increased with the length of exposure and intensity of the light. What made the change in the electrical condition of the plate? Clearly one of two things: either the light was imparting positive charges to the zinc, or else it was dislodging negative charges from it. To find out, Hallwachs first charged the plate negatively and then again stimulated it with light. Gradually it lost its negative charge and once more assumed the positively charged condition. Hallwachs at that time, to be sure, could not explain why the change occurred. Today we believe that the ultraviolet light was stirring up the electrons in the zinc plate and chasing some of them away, leaving the positively charged nuclei behind. Moreover, this pioneer investigator was at the very threshold of the discovery that beams of light could dislodge electrons from a metal plate and cause them to flow away over a conductor as a feeble electric current. This is the very nature of the interaction between light beams and metal surfaces that produces photoelectric effects which give almost certain promise of the extension of television in the very near future. Developments in television will be presented later. Here we shall concern ourselves only with the fundamental principles involved so that we may be ready for the application.

Many other metals exhibited this same photoelectric effect; in fact, some are much more prolific in the production of traveling electrons when stimulated with light than is zinc. Subsequent study has also revealed that although the shorter blue, violet, ultraviolet, X-ray, and gamma-ray waves are especially effective in dislodging electrons from metal surfaces, nevertheless longer waves, even the infrared ones, dislodge electrons, too.

At this point we must pause to note and emphasize two highly important principles that dominate the process of the production of an electric current by radiant-energy waves. The first is that the intensity of the impinging ray (and by that we mean the brightness of the light) has but one effect: to determine the number of electrons dislodged and expelled from the metal plate. It does not affect in any sense the speed at which the electrons travel. To be more specific, a very faint blue ray of light would send a tiny stream of electrons off at a certain speed. Were one now to intensify the same ray a thousand times, he would by comparison dislodge literally billions more of electrons, but they would all travel at exactly the same velocity as the tiny stream expelled by the feeble ray. There would be no difference in their speed. Conversely, the length or frequency of the impinging ray—in other words, the kind of light as to wave length—has everything to do with the velocity of the ejected electrons but absolutely nothing to do with the size of the crowd of electrons leaving the plate. For example, a violet ray of given intensity, let us say, would stir up a definite number of electrons which would travel at a certain velocity. Now, if an X ray of exactly the same intensity be substituted, the crowd of electrons torn loose from the metal and emitted would be the same in magnitude. But, on the other hand, there would be a decided difference in the speed at which the electrons traveled in the two cases. Those sent out by the X-ray beam would travel with a much higher velocity than those emitted by the violet beam. The speed of the former as compared with the latter would be as the velocity of an Indian's arrow to that of a baseball.

Questions for Study

1. With what types of radiant energy is the average person concerned in the daily activities of life?

2. What energy principles are involved when one takes a photograph?

3. How is sight believed to be produced?

4. How would you explain the statement that no two persons ever see the same rainbow?

5. Why were all attempts to explain the origin of radiant energy, previous to about 1895, erroneous?

6. What evidence can you give that radiant energy may be either wavelike or corpuscular in form?

7. Explain why, according to modern theory, heat applied to a stove in sufficient quantity makes it glow.

8. Why is white clothing cooler in the summertime than dark-colored clothing?

9. How does the physicist attempt to explain the difference in color between a red and a green garment?

10. How have X rays been of service to you in your personal experience?

11. How is sunburn believed to be produced?

12. Can you explain why some scientists believe that it may be found possible to detect the location of an airplane on a pitch-dark night from the hot exhaust gases?

13. How does the passage of an electric current through the highly resistant filament of a light bulb cause it to become a source of illumination?

14. How does the use of a large telescopic reflector enable astronomers to detect the presence of celestial bodies far beyond the limits of visibility to the unaided eye?

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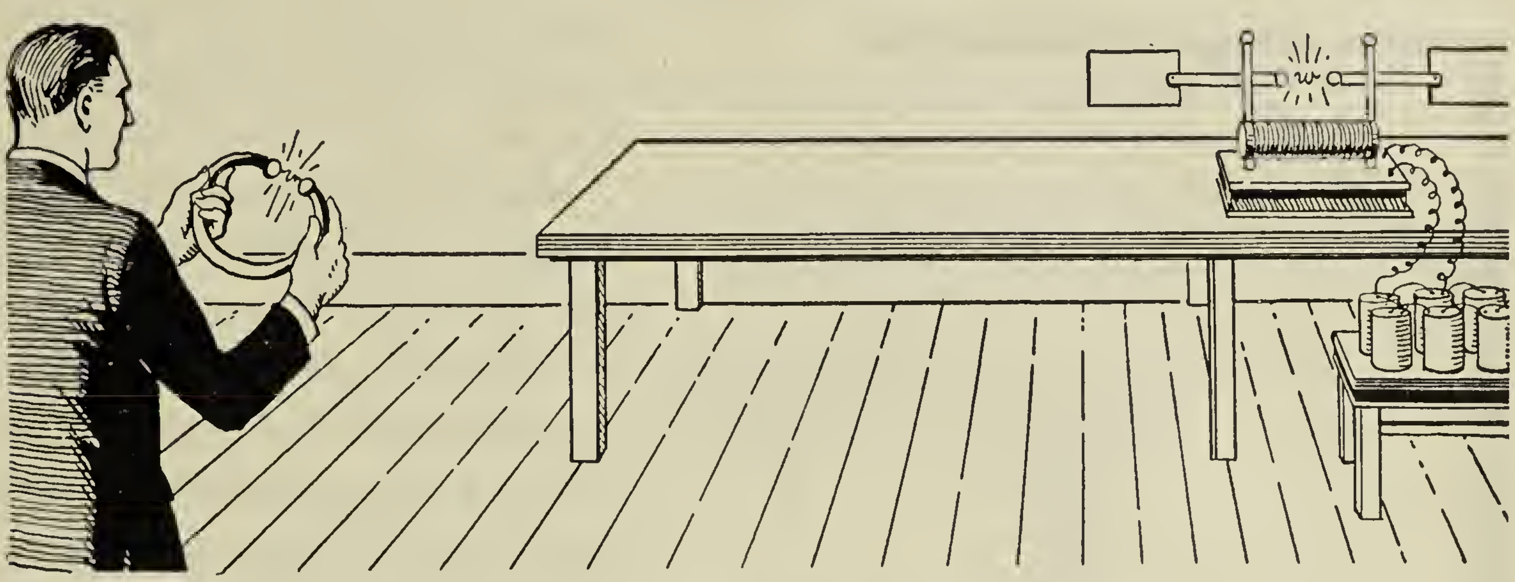
CHAPTER TWENTY-TWO

Radiant Energy Has a Wide Range of Application

An Electric Spark May Be Transmitted through Space. It has been said that "radio was born in a mathematical equation." Clerk Maxwell, an English mathematician of great repute, had become interested in the phenomena of light and electricity. Maxwell was not a practical experimenter; but from certain equations which he had developed he found that a striking similarity existed mathematically between the behavior of light rays and electromagnetic manifestations. Finally, as a result of a series of many abstract and complicated calculations, he reached the definite conclusion that all forms of radiant energy are nothing more nor less than electromagnetic disturbances propagated as waves through space.

Maxwell's conception was a fascinating one; yet it involved such difficult mathematics that it was hard for the practical physicist to understand it. Moreover, it appeared much more difficult to verify experimentally. Many workers tried it, but for one reason or another failed. One day the celebrated German physicist Helmholtz suggested to one of his brilliant assistants, Heinrich Hertz, that he undertake the task.

Hertz's first problem, as is obvious, was to determine whether or not electromagnetic waves, which, like light, would travel through space without a wire to conduct them, could be produced in the laboratory. He experimented with a Leyden jar and with a separate flat coil of wire so wound that the ends were close together, leaving a narrow air gap between them. He connected the outside and the inside of the jar by wires and discharged it. This produced a sharp spark between the opposite extremities of the connecting wires, which had been so arranged as to form an electric gap. At this moment Hertz's alert eyes detected the flash of a tiny discharge between the extremities of the flat coil some distance away. To the casual observer this feeble induced spark might have been but a passing incident, but not so to Hertz. Once again time had brought together a great phenomenon and an ingenious mind that could grasp its significance. Hertz improved his apparatus. He set up an induction coil with a square sheet of metal attached at the outer ends of the secondary terminals and so arranged as to leave a half-inch spark gap. He made a ring which was not closed but which had a gap left at the interruption. Now, standing at one end of the laboratory with this ring in his hand, he caused a series of sharp sparks to be produced between the terminals of the induction coil at the other end of the room. Simultaneously a corresponding series of flashes crossed the gap in the ring in his hand. The great discovery had been made. Electromagnetic waves do travel through space, just as light and other forms of radiant energy do. Clerk Maxwell's contention, first made twenty-five years before, had now, in 1888, been substantiated.



Hertz transmits an electric spark through space[1]

When Particles Are Electrified, They Tend to Cohere. Soon after Hertz had discovered wireless waves it was suggested to him that this principle might be utilized to operate a wireless telephone. He felt the idea to be quite impossible, however, because he did not believe that a telephone-receiver disk could possibly respond to the rapid and delicate electromagnetic vibrations such as he had produced.

Several years before Hertz's work an observation had been made that when particles of dust are excited electrically from a suitable distance they tend to cohere into strings or flakes. In 1856 a man by the name of Varley had utilized the same principle in perfecting a lightning arrester to protect telegraphic apparatus. Varley cut the ground line which was to conduct the lightning from the telegraph line to the ground, where it might be dissipated without injury, and in the gap formed by severing the wires he set a glass tube. He then filled the tube with metallic powder in such a way that the ends of the wire were in contact through the metallic particles. The ordinary electric current used for telegraphing did not affect the coherence of the particles, and in their loose condition they offered a high degree of resistance. However, when a high-frequency rapidly oscillating current occurred, such as a bolt of lightning, the particles instantly cohered and conducted the atmospheric charge to the ground when it came racing along the wire. This coherence tube as later perfected was really a very great discovery, and prepared the way for the first successful attempts at wireless transmission.

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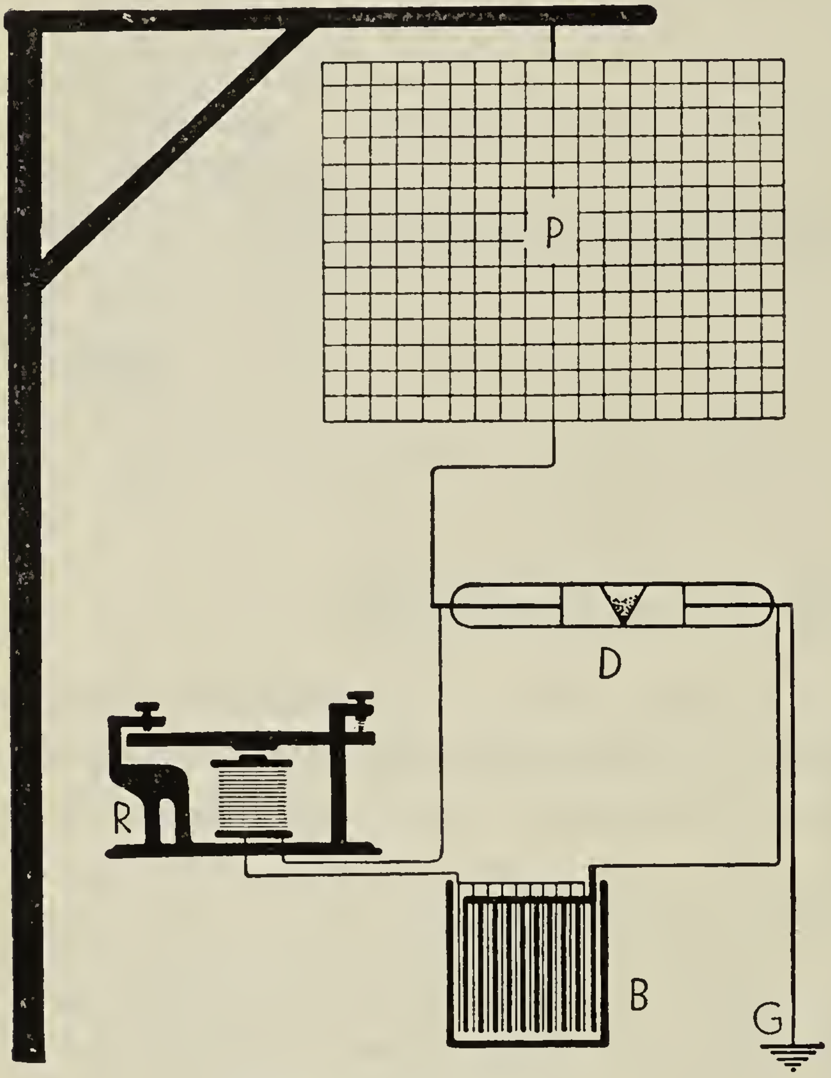
[1] From *Magnetism and Electricity*, by Morris Meister. By permission of Charles Scribner's Sons, publishers.



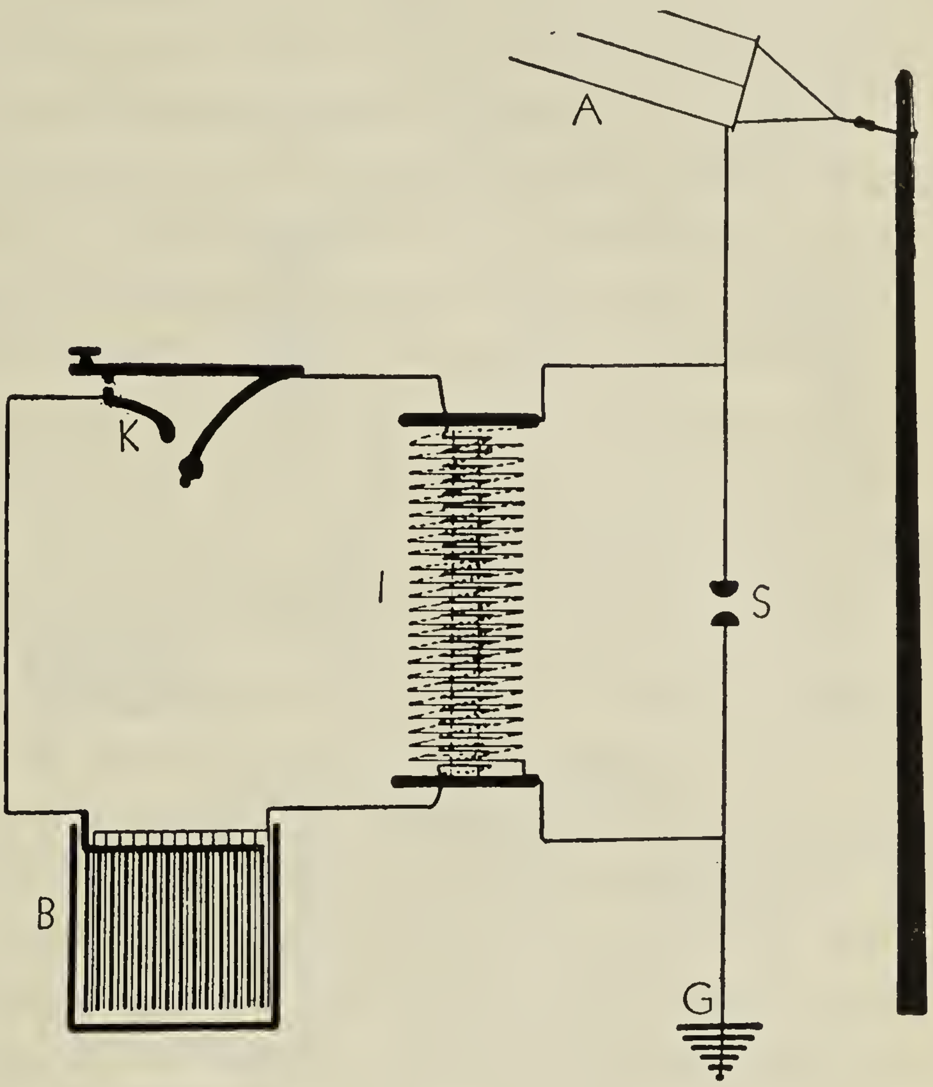
Marconi's receiving set

P, capacity area; *D*, coherer; *B*, battery; *G*, ground; *R*, receiver

Marconi Perfects the First Wireless Telegraph. The first man to apply the principle of the Hertzian waves to wireless communication as well as to make it a commercial success was Guglielmo Marconi, an Italian. Stimulated by one of his teachers, he directed his attention to communicating by wireless waves. At first he experimented on a small scale, but he seems to have quickly grasped the full significance of wireless possibilities. For a long time Marconi could not believe that other men before him had not done the like. He confidently expected to see some announcement of practical signaling by wireless. He searched the technical papers for a year, but nothing of importance was found. Consequently he set himself to the task of improving his apparatus and using the Hertzian waves to transmit messages.

At the outset he was able only to send his waves across the table at which he worked. In a short time he was able to signal across the garden. He improved his coherer tube and arranged an electrically controlled tapper to strike it and again decohere the particles after each electrical impulse had brought them together. The tapper was a device much like an electric bell with the bell part removed. This alternate closing and breaking by the coherer of the current from a local battery in the receiving set worked a telegraphic sounder, and the letters could be read off by ear as in any telegraph office. Marconi found the incoming impulses, or waves, were so weak that their ability to affect the receiving set was greatly increased by the addition of what he called a capacity area. This was a crude form of what we today know as the antenna.

The sending set consisted of a high-frequency induction coil connected through a Morse key to an electric battery. In principle this exciter was little more than a spark gap consisting of two specially mounted metal balls. One side of the gap was connected with the earth, and the other with the antenna. The duration of the spark through the exciter was controlled by the operator working the key. The spark produced electromagnetic (Hertzian) waves which we today call radio waves. These traveled in all directions through space and were picked up by a receiving set at a distance. Thus, as stated by his former teacher, whose encouragement had stimulated him, "Marconi carried into the domain of practical reality that which had only floated vaguely before the minds of others, or had served them for modest experiments." Sir William Preece stated the same idea more forcefully when he said, "They all knew the egg, but Marconi showed them how to make it stand on end."



Marconi's sending apparatus

A, antenna; *B*, battery; *G*, ground; *I*, induction coil; *K*, key; *S*, spark gap, known as the exciter

By constant study and experimentation carried on part of the time in Italy and part of the time in England, Marconi gradually increased the range of his apparatus. At length he established a sending station on the Isle of Wight and installed a receiving set on a ship which cruised about in the adjacent sea. He was able to communicate with the ship when at a distance as great as eighteen miles. Other triumphs followed. In due time a number of shore stations were established, and several ships of the English navy were equipped with wireless. Some of the German steamship lines adopted wireless communication also. In 1900 an incident occurred that demonstrated in a dramatic manner the practical value of wireless and initiated its use as a commercial enterprise. The

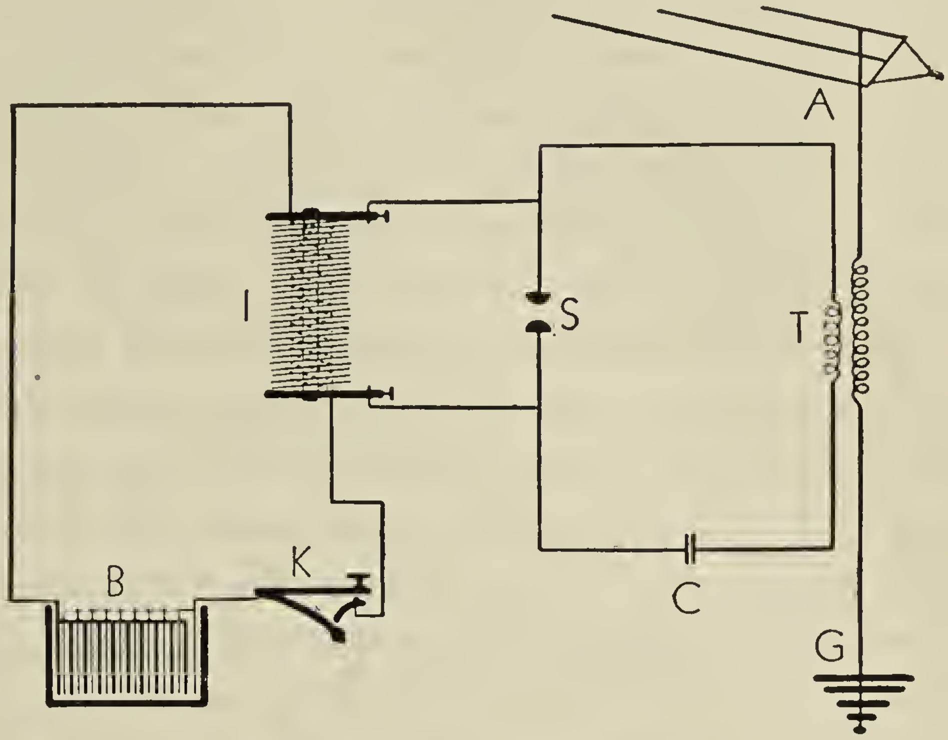
Borkum Riff lightship was equipped with wireless apparatus, and during a storm broke its moorings and was driven out to sea. Its distress signal was picked up, and rescue ships were immediately dispatched to its relief. The whole crew, which otherwise might have perished, was saved.

Syntony, or Tuning, Is Introduced. One of the great objections to Marconi's system which developed at an early period was the disorder and interference occasioned by so many stations. As the method developed commercially, every new transmitter added to the general confusion and chaos. This situation threatened to place serious limitations upon the utility of wireless communication. Sir Oliver Lodge suggested that improved results could be realized by tuning. This was a device whereby a station sent out waves of a desired length only, and the receiving set wishing to pick up its message was adjusted to respond exclusively to that length of wave.

The contrivance for tuning is analogous in its action to a musical string set into sympathetic vibration by another string vibrating at a distance. If the receiver is properly tuned, the cumulative effect of the incoming waves piles up and makes an impression; if it is out of tune, the waves arrive out of step or at a frequency that does not correspond to that of the receiver, and thereby are lost. This same principle developed and perfected is, as the reader well knows, applied to radio today. Each transmitting station is required by law to use a certain wave length. Then when the private individual wishes to pick up any particular station he simply turns the dial on his receiving set until it responds to the wave length which he wishes to intercept. This is called "tuning in," and the term explains exactly what is done. In this way space may be literally a confusion of radio waves sent out by different stations; but the listener is perfectly oblivious to this chaos, because the selective tuner on his receiver is receptive only to those wave lengths in which he, for the time being, is interested.

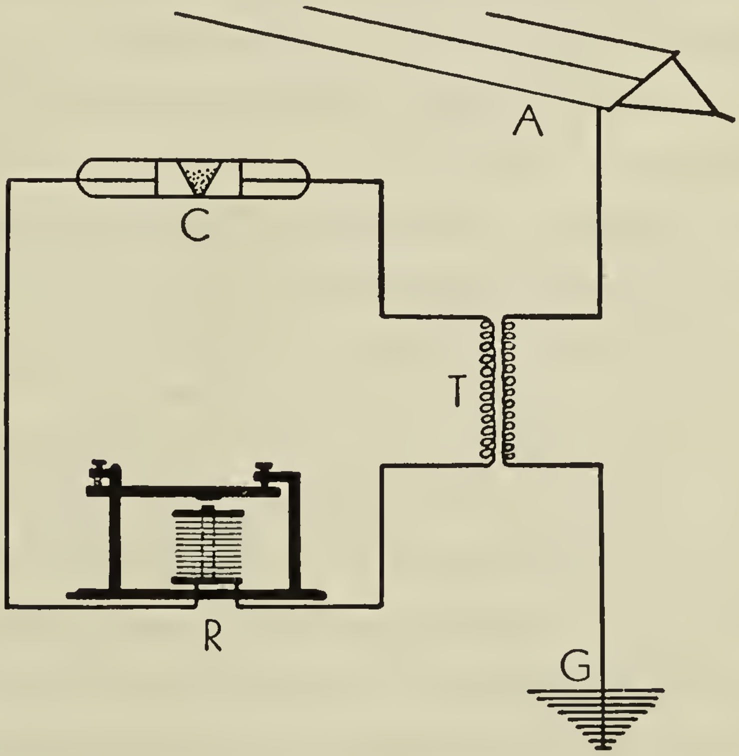
In 1900 Marconi constructed a very much improved wireless apparatus which not only incorporated the principle of tuning but also introduced a condenser and a second induction device. In his first apparatus the aerial was charged directly from the first induction coil. The amount of sending energy thus developed was small, the waves were highly damped, and their power was rapidly diminished as they traversed space. In his new apparatus the battery circuit of the transmitter was essentially the same as in his original set; but the secondary circuit with its spark gap was closed and also contained both a condenser (a modified Leyden jar) and a tuning coil. The tuning coil now induced an oscillating current of high frequency on a coil set in the wire connecting the antenna with the earth. These two circuits were tuned, one with the other, by means of the coils. This caused the oscillations, or surge of the current set up by the rapid charge and discharge of the condenser through the spark gap, to be repeated, by induction in the aerial, as induced oscillations. This surge of electrons up and down between the antenna and the earth then produced the radio waves that traversed space in all directions. This induced oscillating energy in the antenna was not only much more powerful than in the original set, but the amplitude of the transmitted waves decreased only slowly, which gave them the power to penetrate a much greater distance because the energy was concentrated on one frequency.

The receiving set was similarly improved. The ground wire from the aerial included a coil which induced a secondary current in the circuit containing the coherer. These coils were tuned not only with each other but also with the tuning coils at the transmitting station. All four circuits were thus tuned with one another, and the possibility of highly selective long-distance wireless communication had been realized.



Marconi's tuned transmitter

A, antenna; *B*, battery; *C*, condenser; *G*, ground; *I*, induction coil; *K*, key; *S*, spark gap; *T*, tuning coils



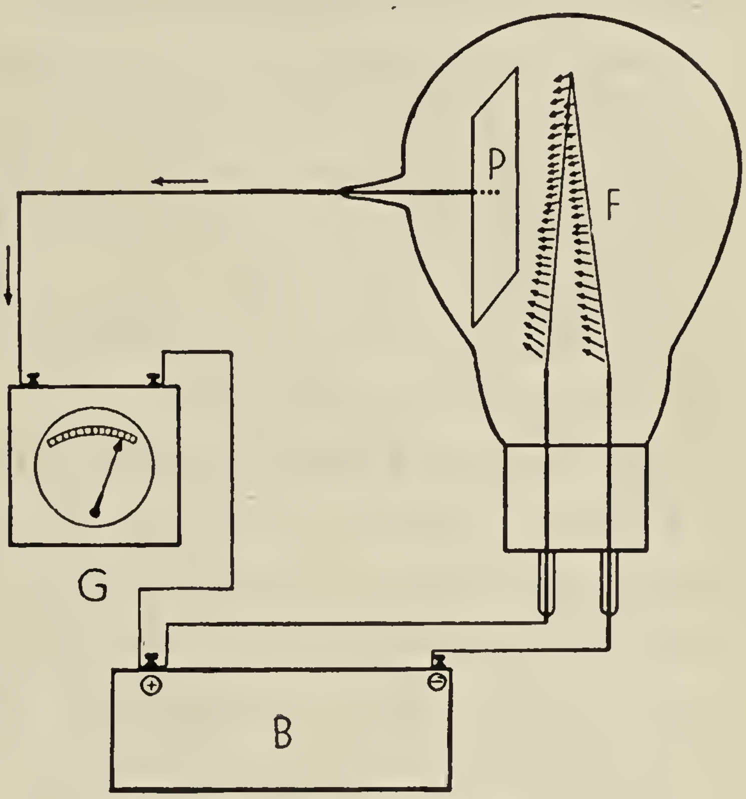
Marconi's tuned receiving set

A, antenna; *C*, coherer; *G*, ground; *R*, receiver or sounder; *T*, tuning coils

As interest in his system grew apace, Marconi turned his attention to spanning the Atlantic with wireless messages. On December 6, 1901, he arrived in Newfoundland to see if he could pick up the waves from a powerful station which had been erected in Cornwall, England. With the aid of two assistants he attempted to elevate a long antenna wire by means of kites; but the first kites were either lost as they severed their lines or were swept out to sea. A fourteen-foot balloon filled with hydrogen also snapped its mooring line and disappeared into the heavens. Finally on December 12, in the face of a gale, they succeeded in getting a kite up which raised an antenna wire to an elevation of four hundred feet. Marconi stationed himself before his receiving set in a room of an old barrack and listened for the prearranged signal, which was to be sent out continuously from the station two thousand miles away. For half an hour no sound could be detected. Then suddenly, faintly but distinctly and audibly, came in the three little clicks, the dots of the letter "s," which were to be sent out. Marconi's ambition had been achieved. A new era of international communication had been opened up—a type of communication which was destined not only to facilitate official and commercial intercourse but to save thousands of human lives and millions of dollars' worth of property on board distressed ships.

The Vacuum Tube Has Greatly Facilitated Wireless Communication. One of the wonderful inventions produced in recent years is the vacuum tube. Thomas Edison made the initial discovery. In the early days of his work on the incandescent lamp Edison noted that the glass bulb gradually became darkened as if covered on the inside with a fine deposit. At length the bulb would become so blackened as greatly to impair its light-giving qualities. Edison decided to investigate this unexplained action. He set a small metal plate inside the bulb so as to extend down in such a manner as to divide the space between the wall and the filament. The plate was thoroughly insulated from all other metal parts of the incandescent light and was made with a connection which was fused through the glass covering to the outside. In the course of his investigation, by connecting this plate with the positive pole of a battery and illuminating the filament with a current, as in the illustration on page 385, Edison discovered that an electric current flowing from the plate to the battery could be detected by a galvanometer. This discovery was made long before the existence of electrons had been suggested, and there was no closed connection between the luminous filament and the plate. Edison rightly concluded, in puzzling over this curious action, that the current must leap across the gap between the filament and the plate. But how this occurred he could not explain. For several years this unexplained phenomenon was known as "the Edison effect."

This is explained today on the assumption that in an electrical conductor free electrons move chaotically about in all directions from atom to atom. When this conductor is made a part of an electric circuit, the electrons are pushed along in one direction by the electromotive force, and the movement of the electrons forms the current. If the electron-producing surface is heated, the dance of the electrons is greatly intensified; and if it (in this case the filament) is made very hot, the electrons, like water molecules from an evaporating surface, fly off in all directions. It is in conformity with electron action, then, that electrons leap across the gap from the hot filament to the plate and in turn race from it in a stream (electric current) to the positive terminal of the battery.



The Edison effect

Electrons flow from the negatively charged filament *F* to the positively charged plate *P*. The filament is heated by the battery *B*. The flow of electrons from the plate is registered by the galvanometer *G*

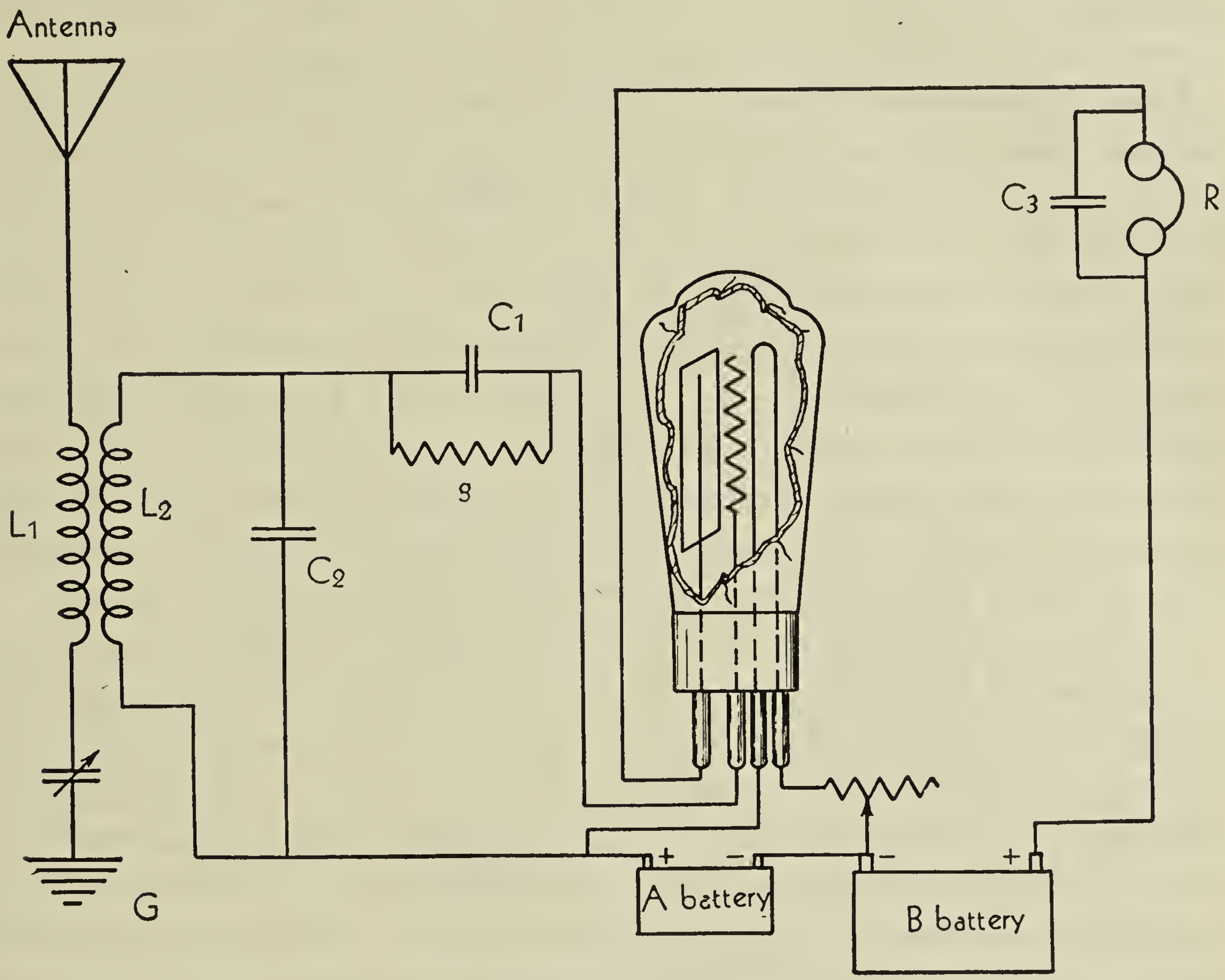
Sir John Ambrose Fleming modified this electron valve by bringing the plate closer to the filament and bending it around the latter in the form of a cylinder. The efficiency of this electron valve was thus greatly increased, because the cylindrical plate arrested the electrons as they departed from the filament on all sides and thus greatly increased the strength of the outgoing current.

The next great step in the development of the vacuum tube was contributed by Dr. Lee De Forest and others about 1907. What is known as a third electrode, or grid, was added. This consists of a wire, netlike cylindrical sheet set between the heated filament and the solid metal plate. The grid is suspended by a rigid wire which is fused through the wall of the bulb. The grid controls in a most ingenious manner the flow of electrons passing between the filament and the solid plate. It is well known that unlike charges of electricity tend to attract each other and that like charges repel each other. Consequently, if a surge of electrons be induced on the grid, it will act as a repellent to the stream of electrons leaving the hot filament, and in this manner materially decrease, if not altogether cut off, the current reaching the plate which leads to the battery. On the other hand, if the electrons surge off the grid, it becomes positively charged and tends to pull off a very much heavier flow of electrons from the hot filament than would otherwise leave it. Some of these electrons will strike the bars of the grid itself, but by far the greater part of them will shoot on through the meshes of the grid to the solid metal plate. In this way the current flowing out from it will be greatly increased above what it would be if the grid were not interposed. In modern radio tubes both the plate and the grid are cylindrical, thereby enabling them to influence the movement of electrons on all sides of the emitting filament. In other ways vacuum tubes today have been modified and greatly improved. In their modern form they control radio reception, radio transmission, wireless telephony, and speech amplification.

The Vacuum Tube Is Applied to the Principle of Radio Reception. Radio, or Hertzian, waves travel through space with the speed of light. As has been found, they are electromagnetic disturbances that induce a feeble current upon any conducting wire which they may sweep past. The aerial of a receiving set, then, is erected for the specific purpose of intercepting these electromagnetic waves generated and sent out by radio stations. Owing to the character of the waves the type of current induced is an oscillating, or alternating, one of very high frequency. According to the accepted theory there is produced at one instant a surge of electrons from the antenna to the earth through the ground wire. The electrons in this manner become depleted in the antenna and conducting wire, causing both the latter to take on a positive charge. At the same instant the electrons tend to pile up in the earth, so to speak, producing a negative charge there. Then, immediately after, there is a surge of the electrons back up the wire and the antenna to restore potential equilibrium. Another incoming wave drives the electrons down again, and thus the current, oscillating several million times a second, is maintained. The ground wire is furnished with an induction coil L_1 (see the illustration on page 387).

Essentially, the receiving set consists of an A battery to heat the vacuum-tube filament, and a B battery to provide the plate current. As the oscillating current on the antenna and its ground connection surges through coil L_1, a corresponding current is induced on coil L_2, which is set in a circuit connecting the grid in the tube and the positive terminal of the A battery. The plate of the remaining circuit is connected with the positive terminal of the B battery, the negative pole of which is brought in contact with the negative terminal of the A battery by means of a connecting wire.

When a stream of electrons is surging over coil L_1, electrons by inductive repulsion are crowded out of coil L_2 over the wire and through the condenser C_1 into the grid. The strength of the negative charge is controlled by the values of grid leak *g* and the condenser C_1. The grid, now taking on a stronger negative charge from coil L_2, by repulsion cuts down the flow of electrons through it from the filament across to the plate. Consequently the current flowing in the circuit of which the *B* battery is a part is diminished. On the other hand, if coil L_1 be positively charged, electrons by attraction are pulled from the grid to coil L_2, thereby causing the strength of the negative charge on the grid to be reduced. As a result, the flow of electrons from the filament through the grid across to the plate is now greatly enhanced, and the current flowing in the *B* battery circuit is commensurately increased.



Radio receiving set

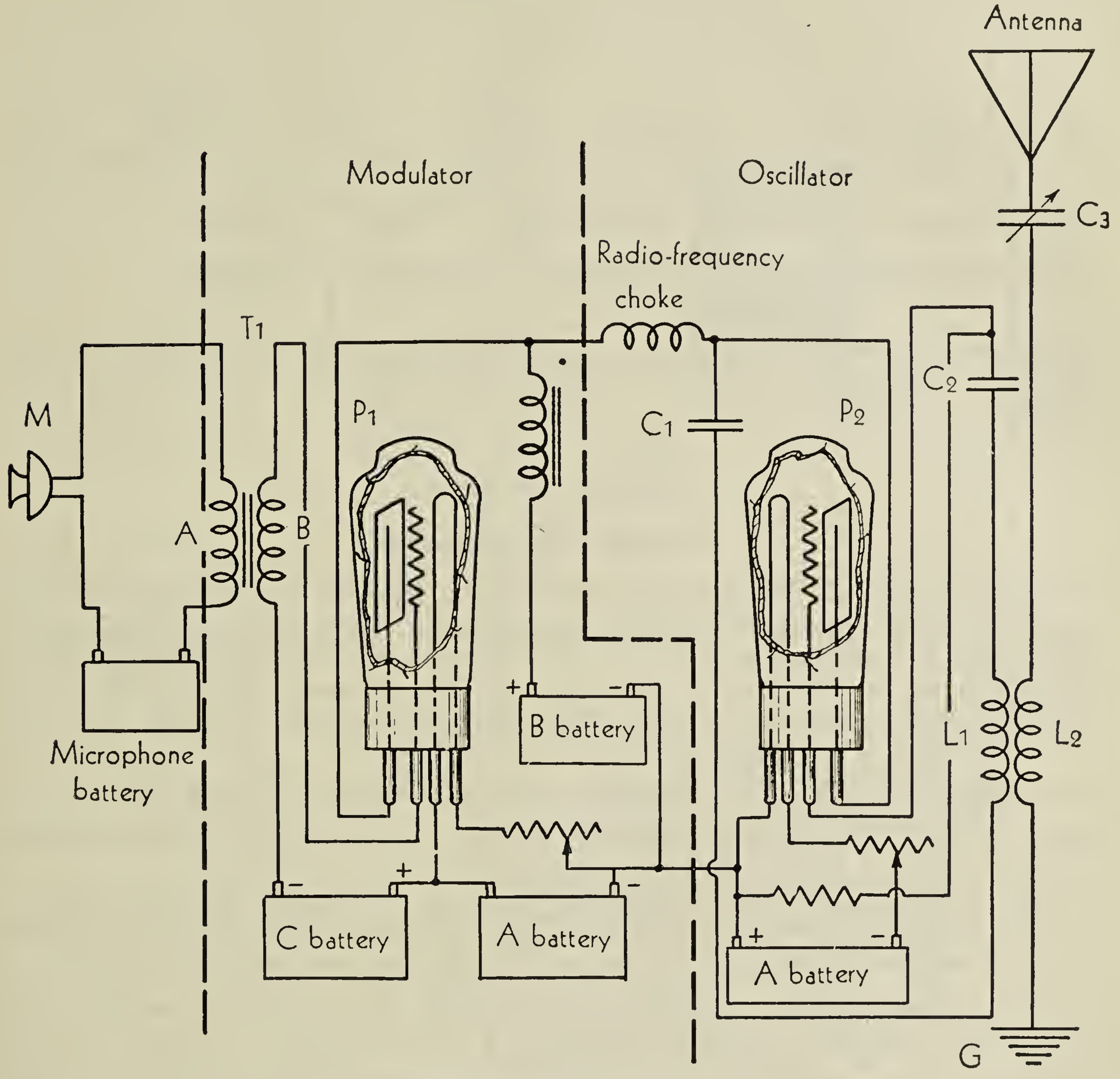
It is obvious that any modification of the aerial oscillations in respect to either amplitude or character will be transmitted through the vacuum tube and will in turn be faithfully reproduced in the *B*-battery circuit. Moreover, the oscillations will at the same time be greatly intensified. So, then, this single-tube receiving set becomes at once both a detector and an amplifier. If now a loud-speaker or a telephone receiver be set in the *B*-battery circuit, the exact tones, either of voice or of musical instrument, which were originally sent out from the broadcasting station will be reproduced. If more distinct and audible tones are desired, or if the listener wishes to pick up faint waves coming from more distant stations, this too can easily be accomplished. It is achieved by adding more vacuum tubes, in a sort of relay fashion, to intensify the current finally delivered to the earphones or the loud-speaker.

Radio Transmission Makes Use of the Basic Principle Underlying the Vacuum Tube. The vacuum tubes used in radio broadcasting are exactly like the ones used in a receiving set, except that they are a great deal larger and more powerful. In broadcasting, the voice of one speaking into the microphone *M*, for example (see figure on page 389), varies the current flowing through it much as one's voice varies the current flowing through a telephone transmitter as one speaks into it. The varied current from the microphone flows through coil *A*, which in turn induces a current in coil *B*. These primary and secondary coils of T_1 constitute a step-up transformer, which, in radio terminology, is known as an *audio transformer*, because the current produced by the action of the microphone can be made to produce audible sounds.

It is seen, too, that one extremity of the secondary coil of the transformer T_1 is connected to a *C* battery. This battery is included for the purpose of placing a continuous slightly negative charge on the control grid of the vacuum (or radio) tube P_1. When the current induced by the microphone circuit flows in the secondary coil of T_1, the negative charge already residing on the grid circuit is either enhanced or diminished in proportion to the induced current coming over through the transformer. As the strength of the charge on the grid varies, so also will the number of electrons vary that flow from the filament across to the plate through the grid. In this way, then, the current flowing from the plate through the *B*-battery circuit will vary in response to the strength of the current induced on the *C*-battery circuit.

This *B*-battery current varied by the tube P_1 (called a *modulator*) flows through R.F.C. (radio-frequency choke) to the plate of the tube P_2, where it is impressed upon the residual plate current already flowing in that tube. This radio tube P_2 is so connected in its circuit as to become a generator of an alternating current of a definite frequency. For this reason, in radio language, it is known as an *oscillator* and works as follows: When the current originating at the plate in P_1 flows to the plate of P_2, it will be varied, or modulated, by tube P_1. This modified current is then known as a *modulated radio-frequency* current. This modulated current now flows through condenser C_1 through coil L_1 and then through condenser C_2 to the grid of the tube, where the grid acts to vary the current, as explained for tube P_1. The function of R.F.C. is to prevent oscillating currents originating on the plate in tube P_2 from getting back to tube P_1.

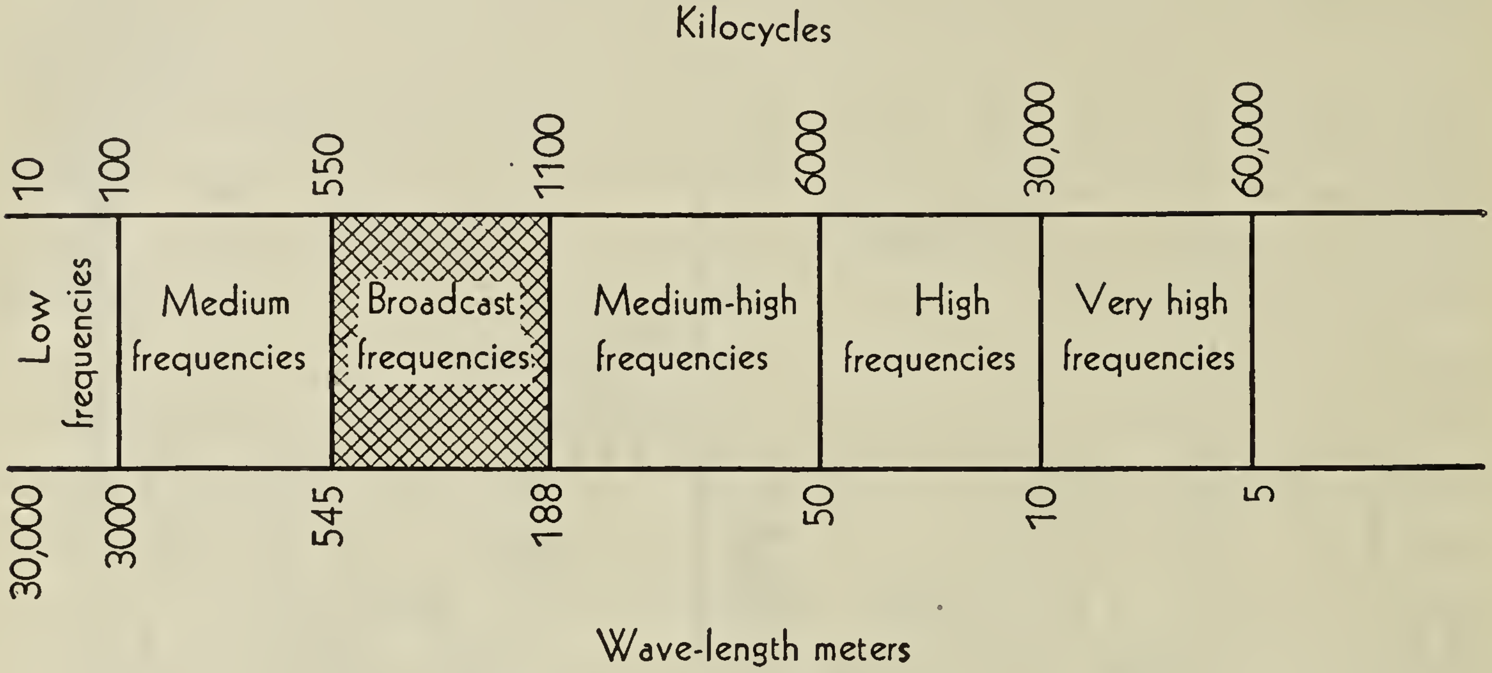
As the modulated oscillating current flows through the primary coil L_1, it induces a like current in the secondary coil L_2. The coil L_2 is connected, through the variable condenser C_3, with the antenna. The opposite end of coil L_2 has a lead wire extending to the ground G. When the effect of the induced, modulated oscillating current from L_2 is transmitted through the condenser to the antenna, it causes the latter to send out through the air modulated radio waves, such as are received by our radio sets at home.


Antenna
Modulator
Oscillator
Radio-frequency choke
C3
T1
M
C2
P1
C1
P2
A
B
+
−
B battery
L1
L2
Microphone battery
+
−
−
C battery
A battery
+
−
A battery
G

Radio broadcasting set

There are other ways by which modulation may be accomplished. The one described is known as *plate modulation* because the modulation takes place in the plate circuit. This may also be accomplished, as is evident, in the grid circuit.

The vacuum tube, which is an effective automatic electron valve, has entirely displaced the coherer tube in wireless-telegraph communication. The coherer controlled the current by a variation in the degree of coherence between the particles; the vacuum tube accomplishes the same control by



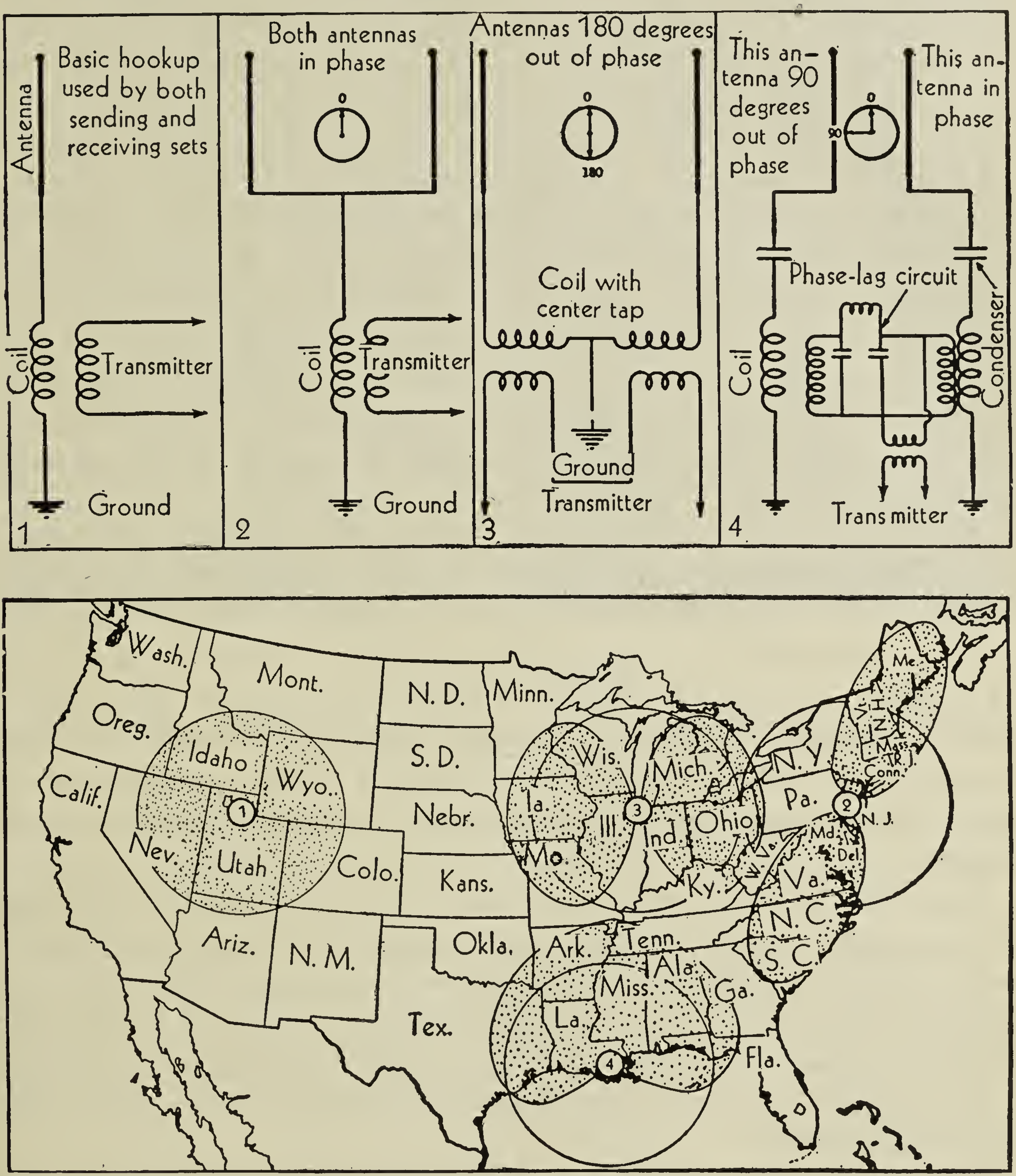
The uses of the frequencies

Low frequencies are used for commercial point-to-point, high-power, and long-distance broadcasting; medium frequencies, for commercial communication, ship-to-shore, telegraphic, and government messages; medium-high and high frequencies, for general communication, experimental broadcasting, experimental television, government wireless and amateur aviation; very high frequencies, for general experimental amateur broadcasting and government commercial broadcasting

the action of the grid. As a regulator and detector the vacuum tube is much more sensitive and efficient than the coherer. It is for this reason that the tube has completely superseded the latter.

The Vacuum Tube Has Made Possible Present Radio Communication. One of the most important advances in radio has been the introduction of vacuum tubes and other improvements which have made transmission by shorter wave lengths possible. The original waves, used by the old spark-gap transmitting apparatus, were long ones. They might vary in length, speaking roughly, from about a mile to fifteen or twenty miles. But the vacuum tube and its accompanying improvements made possible the use of higher frequencies with their resulting shorter wave length. While longer wave lengths are still used for special purposes, general commercial broadcasting is done on much higher frequencies. The Standard Broadcasting Band, by which most of our domestic broadcasting is done, ranges in wave length from about 188 meters to approximately 550 meters.

Even these wave lengths, however, are restricted in their practical applications. It takes considerable power to send them, and the distance they travel is limited. It has been found that still shorter waves carry much farther, use less power in transmission, and can be directed to better advantage. As a consequence, a considerable amount of domestic broadcasting and amateur work is now done on short wave, as well as practically all the international broadcasting. These short waves usually range from about 10 meters up to about 175 meters. Experimental work is now being carried on with wave lengths as short as 1 meter or less. Just what use can be made of these shorter wave lengths as a medium of general communication the research of the future must reveal.


Antenna
Basic hookup used by both sending and receiving sets
Coil
Transmitter
Ground
1
Both antennas in phase
0
Coil
Transmitter
Ground
2
Antennas 180 degrees out of phase
0
180
Coil with center tap
Ground
Transmitter
3
This antenna 90 degrees out of phase
0
90
This antenna in phase
Phase-lag circuit
Condenser
Coil
Trans mitter
4
Wash.
Mont.
N. D.
Minn.
Oreg.
Idaho
Wyo.
S. D.
Wis.
Mich.
N. Y.
Me.
Vt.
N. H.
Mass.
R. I.
Conn.
Calif.
1
Nebr.
Ia.
Ill.
3
Ohio
Pa.
2
N. J.
Nev.
Utah
Colo.
Kans.
Mo.
Ind.
Md.
Del.
Ky.
Va.
N. C.
S. C.
Ariz.
N. M.
Okla.
Ark.
Tenn.
Ala.
Ga.
Miss.
La.
Tex.
4
Fla.

Broadcasts are sent out in special patterns to reach predetermined areas

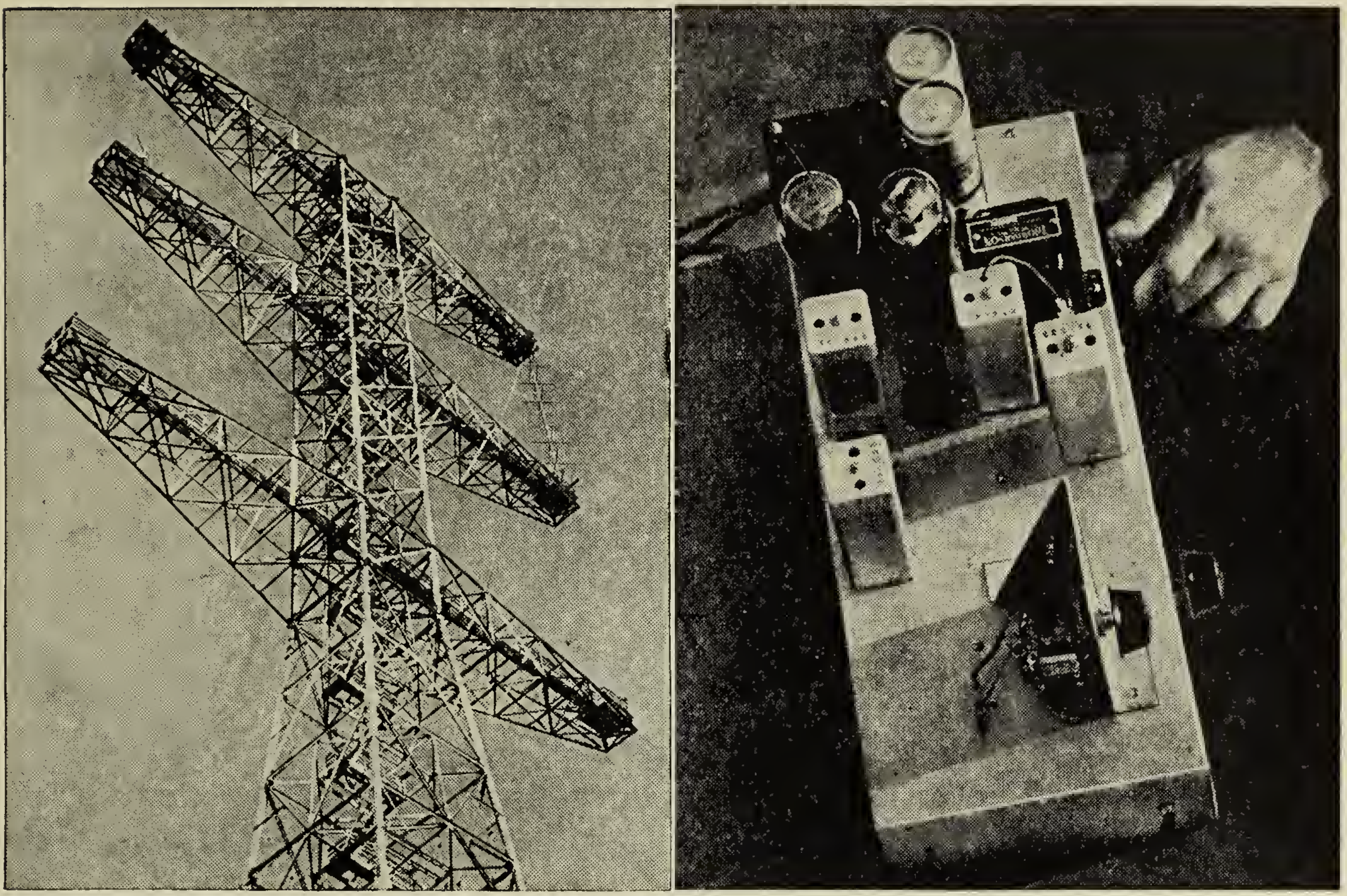
Top, basis hookup and antenna positions. Bottom, pattern produced by each type of circuit

Another advance in radio communication has been that of directed broadcasting. Originally radio waves theoretically penetrated space equally in all directions from the transmitting antenna. In this way the surface area covered by a single station, if any topographical irregularities that might occur be disregarded, was a circle with the sending antenna at the center. For general broadcasting purposes this plan worked very well. There were circumstances and locations, however, in which this type of reception pattern was highly undesirable. A station might be situated on the coast and wish to reach the populace on the mainland rather than waste its energy broadcasting over a vast expanse of uninhabited ocean. Or it might want to send a message from New York, for example, across the sea to England. It might not care to have the carrier waves intercepted by receivers in other directions. Particularly is this true in time of war. Besides, if all the sending energy could be put into a narrow directed pattern, the energy necessary to transmit the message could be materially reduced.

An engineer named Southworth worked out the formulae for pattern broadcasting (see illustration on page 391) and the designs for the transmitting antennae. The first antenna of this type was installed in Florida. Others have followed. Today there are dozens of them at different points in the United States where special pattern-directed broadcasting is desired. Some broadcasting companies in the United States communicate with the South American countries by the use of special fan-shaped patterns. Similar pattern forms are used for other foreign broadcasts, particularly when great distances are to be spanned.

Major Edwin H. Armstrong, an electrical engineer at Columbia University, after ten years of experimentation to get rid of static interference, has perfected a system by which this annoyance can be eliminated. His system uses a high-frequency short wave so modulated as to be unaffected by the static character of either other commercial waves or the "wild" radio waves which may be produced in nature. This system is commonly known as FM (frequency modulation).

In one test a million-volt arc of artificial lightning was shot just a few feet from an FM receiving set without producing a ripple of static. Electric storms which drowned out standard broadcast waves left FM reception almost entirely clear and faithful. Moreover, this type of wave is said to be unaffected by the static interference which comes from the use of electric razors, carpet-sweepers, toasters, and other electric appliances. Another advantage is that because FM uses ultrashort waves, it makes possible an "almost unlimited number of broadcasting channels, providing room for nationwide chains and



Science Service

A B

Frequency modulation

A, 400-foot tower for experiments with frequency modulation; *B*, six-tube receiver designed for reception of frequency modulation

local stations" in great number. The transmitting equipment also requires less sending power, which promises more broadcasting stations and cheaper station operation.

With this system, free from static and other interference, reproduction is surprisingly true. Faint musical notes in a beautiful melody, now frequently lost because they have insufficient volume to ride over the noises, are said to come through with a brilliance that gives one new conceptions of radio fidelity. Homely natural sounds like the scratching of a match or the gurgling of water as it pours from the mouth of a bottle are reproduced with great accuracy.

The chief drawback which the system has encountered is the limited receiving distance which the broadcasting stations can reach. For, as will be more fully explained in connection with television, such ultrashort waves tend to leave the ground at a distance of forty or fifty miles from the transmitter. This is due chiefly to the curvature of the earth. However, because of certain technical advantages, the FM broadcasting station at Alpine, New Jersey, operates effectively to about one hundred miles, or twice the distance that can now be effectively reached by television. It seems possible that these broadcasting limits may be pushed out considerably farther with improvements that may subsequently come.

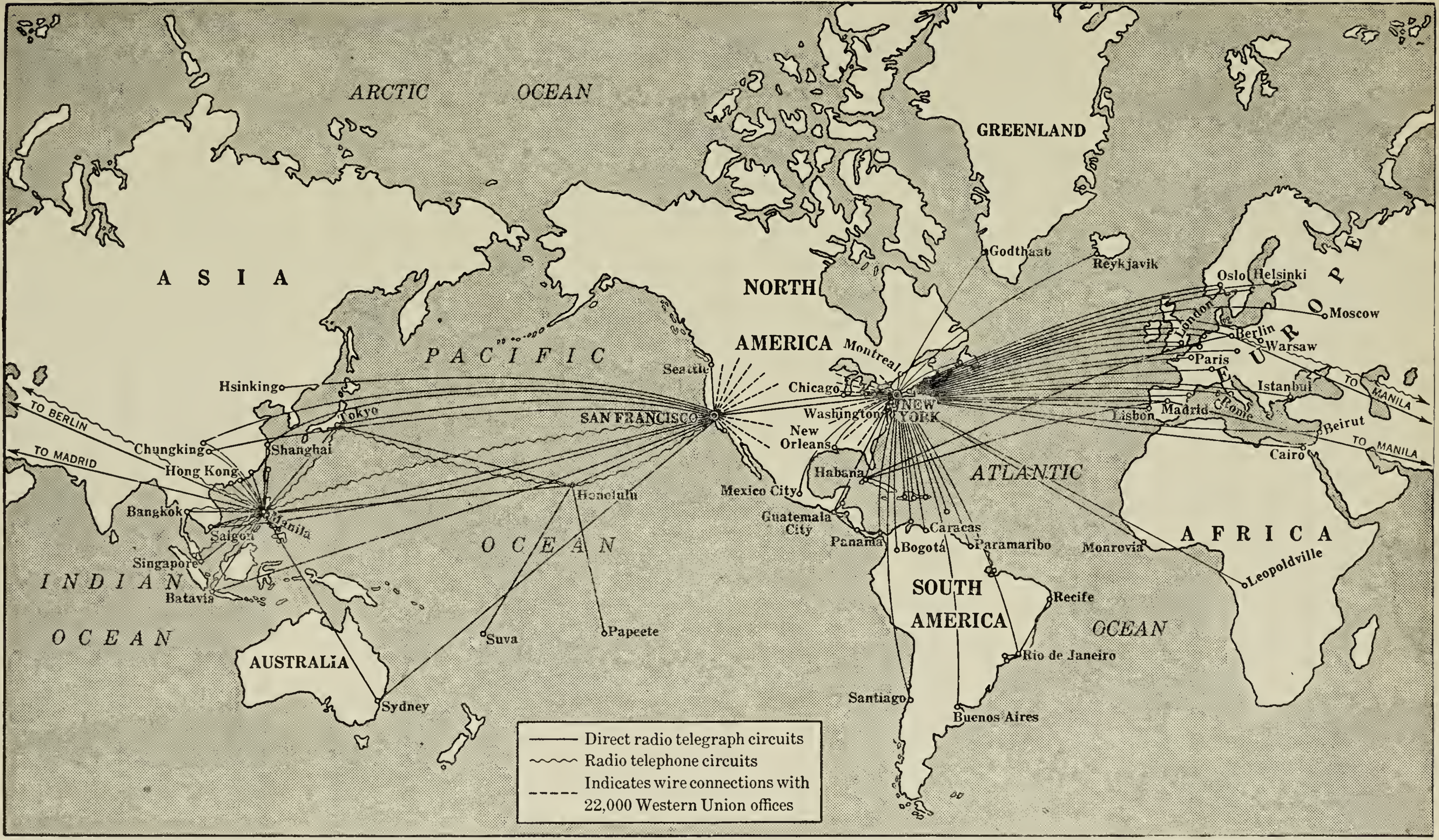
Another disadvantage to the consuming public is that these short carrying waves require a special receiving set. At present there are estimated to be approximately 55,000,000 standard receiving sets in the United States purchased at a cost of approximately $4,000,000,000. To "junk" such an investment and start all over again, as would be necessary if all broadcasting stations used FM, would work a distinct hardship on many people. Such a change will have to come slowly.

Radio Communication Exerts an Important Influence on Modern Society. Everyone is acquainted with the profound influence which modern radio is exerting upon our national life. Important addresses, concerts, and news events are now transmitted from all over the United States. Since about 80 per cent of American homes have radios, it is possible for any individual or organization that can make satisfactory arrangements to reach perhaps 90 per cent of the whole American populace at once. Dwellers in remote districts are as much a part of this audience as citizens of the largest metropolitan areas. Other, more utilitarian services of radio are the following: airplane pilots are kept informed as to the weather and assisted to their destination when storm and fog obstruct their view; forecasts of approaching storms and freezing weather are broadcast to shippers and growers of perishable commodities; police cars are directed in the performance of their duties; mechanized warfare would be quite impossible without radio. In hundreds of other ways modern life is being modified by this remarkable invention.

However wide and significant the influences of the radio may be on national life, they are even more pronounced on international relations. Before the war interrupted, the National Broadcasting Company, to take an example, reported that its system maintained direct international radio service with more than forty foreign countries. Through this medium regular sixteen-hour daily international broadcasting service on short wave was maintained. This regular service was supplemented by many special broadcasts.

In 1938 a series was inaugurated from the South American and Central American countries under the caption "The New World Salutes the Old." Fifteen-minute broadcasts were sent out from stations in those countries three times a week in five different languages. They were designed to acquaint the world at large with the cultural and business life of those nations.

More than one thousand vessels that ply the high seas were served by radio, and this number is mounting, especially during the war, as rapidly as opera-


ARCTIC OCEAN
ASIA
PACIFIC OCEAN
NORTH AMERICA
GREENLAND
EUROPE
AFRICA
ATLANTIC OCEAN
SOUTH AMERICA
INDIAN OCEAN
AUSTRALIA
TO BERLIN
TO MADRID
TO MANILA
TO MANILA
Hsinking
Chungking
Hong Kong
Shanghai
Tokyo
Bangkok
Manila
Saigon
Singapore
Batavia
Sydney
Suva
Papeete
Honolulu
Seattle
SAN FRANCISCO
Chicago
Montreal
Washington
NEW YORK
New Orleans
Mexico City
Habana
Guatemala City
Panama
Bogotá
Caracas
Paramaribo
Recife
Rio de Janeiro
Buenos Aires
Santiago
Godthaab
Reykjavik
Oslo
Helsinki
Moscow
London
Berlin
Warsaw
Paris
Istanbul
Lisbon
Madrid
Rome
Beirut
Cairo
Monrovia
Leopoldville
Direct radio telegraph circuits
Radio telephone circuits
Indicates wire connections with 22,000 Western Union offices

Courtesy of R.C.A. Communications, Inc.

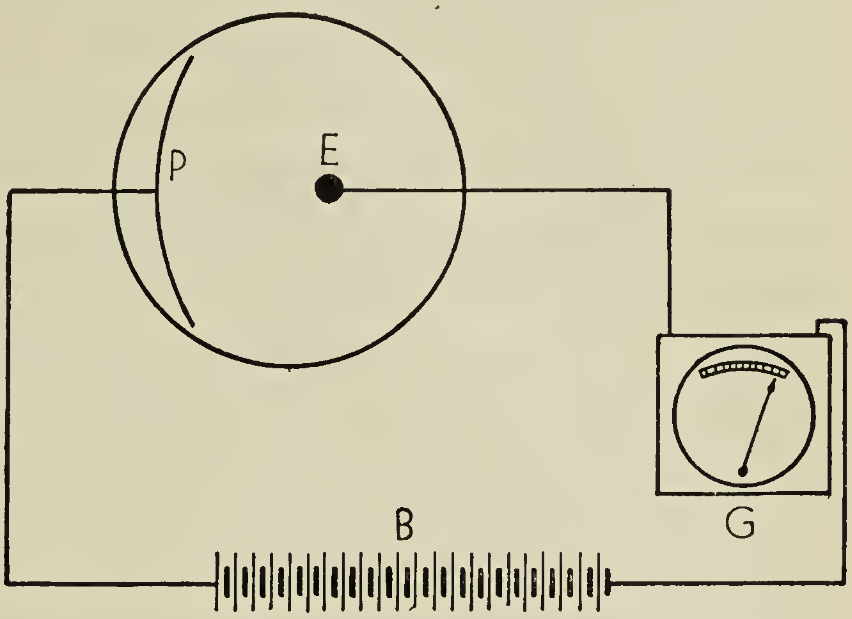
The international hookup of the Radio Corporation of America tors can be obtained. Rapid communication through either radio telegraphy or radio telephony can be established with these vessels. To add to the safety of ocean travel many of these vessels are equipped with automatic radio alarm services installed to receive emergency signals from another ship when the radio operator is off duty. By this installation all vessels, cargo as well as passenger vessels, in a given area can send out their SOS distress calls, and by a system of automatic bells and lights the radio operator off duty on the vessel receiving the call is brought back to his post. In this way assistance may be rendered promptly to boats in distress.

In the course of normal, peacetime communications great numbers of radiotelegrams are sent daily to all parts of the world, and radiotelephone conversations are frequent. This type of service has recently been supplemented by "facsimile" transmission through which pictures, news bulletins, or pictorial information of almost any kind may be sent out. Radiophotographs are now transmitted widely to American newspapers. It is even believed by many that when television is sufficiently perfected, we may read our news through facsimile transmission rather than from the page of the morning newspaper.

On Sunday, October 23, 1938, a broadcast occurred which exhibited in a striking way the power of radio to bring remote regions of the earth together through the medium of communication. The broadcast was conducted from a New York studio by Admiral William D. Leahy of the United States navy. It was dedicated to the observance of Navy Day, Thursday, October 27, 1938. Admiral Leahy proceeded to call by radiotelephone officers stationed on their vessels in various parts of the world and converse with them. Conversations were broadcast between Admiral Leahy and Rear Admiral George J. Myers at Manila in the Philippine Islands, Rear Admiral Lackey on the flagship *Omaha* off the coast of France in the Mediterranean, Admiral Claude Bloch on the heavy cruiser *Houston* in the harbor of Los Angeles, Admiral King in midair on a new naval "flying dreadnought" cruising over San Diego, and various commanders of the Atlantic squadron distributed along the Atlantic coast.

These conversations were not one-way communications; the officers at these various stations talked to Admiral Leahy and to one another with almost as great ease as if they had all been in the same room. Deployment of the ships was discussed, orders for target drill were given and executed, and altogether a most vivid picture of the management of the far-flung vessels of the navy was presented. The climax came near the close of the program. From the training base at New London, Connecticut, the conversations of members of a submarine crew were broadcast as they escaped from a supposedly disabled submarine—in reality, a deeply submerged tank—and rose to the surface of the water in the recently developed "submarine lung."

Formerly it took days, if not weeks in some instances, for the news of an important battle to reach a national capital. In the second World War, however, not only the government but the people of the United States are in daily communication through their radios with almost every important battle front in the world. In addition, the air is full of short-wave propaganda messages sent out by many nations seeking to influence public opinion. Moreover, radio is destined to become an increasing factor in the postwar world.



Photoelectric cell

P, cathode; *E*, anode; *B*, battery; *G*, galvanometer

The Photoelectric Cell Will Produce a Feeble Current of Electricity. Television is just coming into use in restricted metropolitan areas. But before the reader can understand its underlying principle, he must become acquainted with another tube, even more fascinating in its action than the vacuum tube.

It will be recalled that whenever a beam of light falls on the surface of some metals, electrons are agitated, and many of them are dislodged from their positions about the atomic nuclei. Moreover, the number of the electrons is directly proportional to the intensity of the impinging light beam. Since an electric current is nothing more than a stream of electrons, then it is perfectly obvious that if the swarm of dislodged electrons could be gathered up and made to move along a wire, we should have the phenomenon of a beam of light generating a feeble current of electricity. This is the principle upon which the photoelectric cell works.

These cells are popularly known as "electric eyes." A common type consists of a plain, spherical glass bulb, either highly evacuated or filled with some inert gas, such as argon, at reduced pressure. A round disk on one side, called the window, is left plain, while the rest of the inside of the bulb is coated with some light-sensitive metal, such as potassium, caesium, or rubidium. This metal coating becomes the cathode. The central anode, which is insulated from the cathode, may take the form of a small nickel rod so arranged as to leave an appropriate gap between the two electrode surfaces.

When a beam of light passes through the window and strikes the sensitive cathode, electrons are dislodged from this surface. Darting across the space gap the electrons strike the anode, stream down it, and out through the contact point to form an electric current. Such a current is a very feeble one, but by the use of a vacuum-tube amplifier it may be increased to operate an electromagnetic switch. Through this medium, then, a current of any desired magnitude from a generator or a power line may be brought into play. In this manner a beam of light from the star Arcturus was used to open the Century of Progress Exposition in Chicago in 1933. The feeble beam of starlight, focused upon a photoelectric cell, was made to close the switch that turned on the lights and started the machinery of the exposition.

The practical ways in which an electric eye may be employed are almost numberless. The use of sound films, such as are heard at every motion-picture show today, would be quite impossible without the photoelectric cell. A small incandescent lamp shining through the tiny sound track on the motion-picture film excites the photoelectric cell. The modified current produced in this way is amplified by means of a loud-speaker to reproduce the sound which accompanies the pictures. Animals, persons, cigars, eggs, or other objects passing by a registering device attached to an electric eye may be counted, fruit and beans sorted, packaging machines operated, telescopes kept centered on a star, doors made to open and close for a waiter carrying trays, the light intensity of schoolrooms regulated, the beacon lights for airplane landing fields turned on as darkness appears, or the winner of a horse race, when two horses are running nose and nose, may be determined by means of cameras whose shutters are worked by this device.

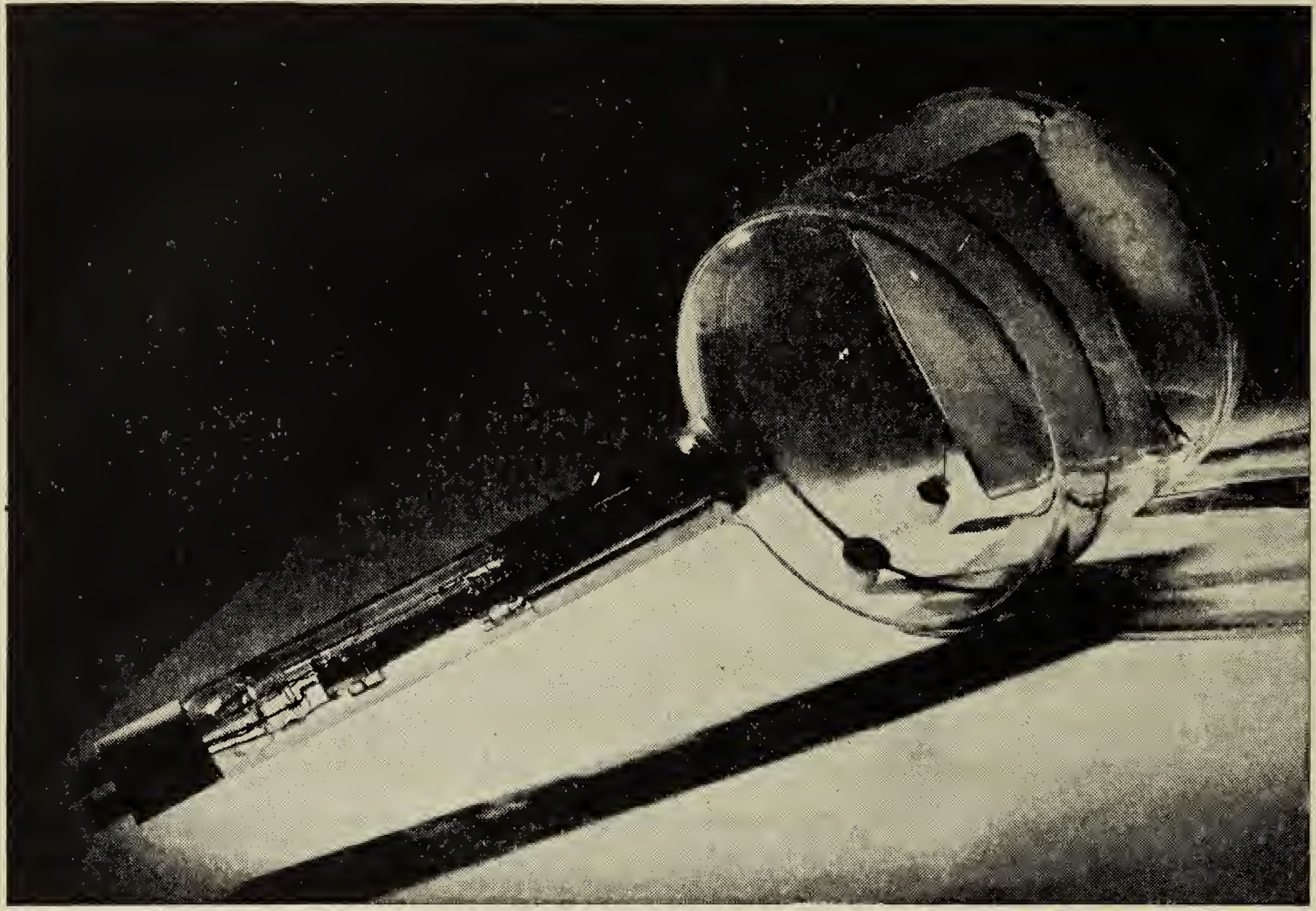
Photoelectric cells sensitive to infrared rays are used in burglar-alarm systems. In this way the longer, invisible heat rays emitted from the burglar's body, even though he works in the blackest darkness, may be made to excite a delicate photoelectric cell. When amplified, the feeble current so produced rings an alarm. Many saboteurs and thieves are being apprehended at war-industry plants by the aid of the "dark" electric eye during the present World War. It has even been suggested that in time photoelectric cells will be perfected to such a degree that they will be able to detect and render visible a bombing plane at night through the long heat rays liberated from the motor exhaust.

The Photoelectric Cell Has Made Television Possible. A photographic plate registers the likeness of the object photographed. This effect is produced because from the multitude of points making up the surface of the object varying degrees of light are reflected back to the plate, where they are faithfully recorded on the negative. If the object is a person's face, some parts of the countenance are comparatively dark, others very light, and still others intermediate in their degree of illumination. All these differences appear on the negative; and when a print is made from this negative, the likeness (lights and shadows) of the person's face is reproduced. In fact, the very similitude of the whole picture—features, outline, and expression—depends upon the degree of exactness with which the photographic plate reproduces the varying amounts of light and shadow appearing on the different points of the person's face at the time the picture is taken.

The same principle is used in television, except that in the television camera there is no photographic plate or film. Instead a "plate," or mosaic as it is commonly known, in the form of a compound photoelectric cell is used. This mosaic resembles a fly's eye in the sense that just as a fly's eye is made up of a great many simple eyes (facets), so this composite photoelectric plate is composed of a great many minute photoelectric cells, each electrically insulated from all the other tiny photoelectric cells which make up the whole.

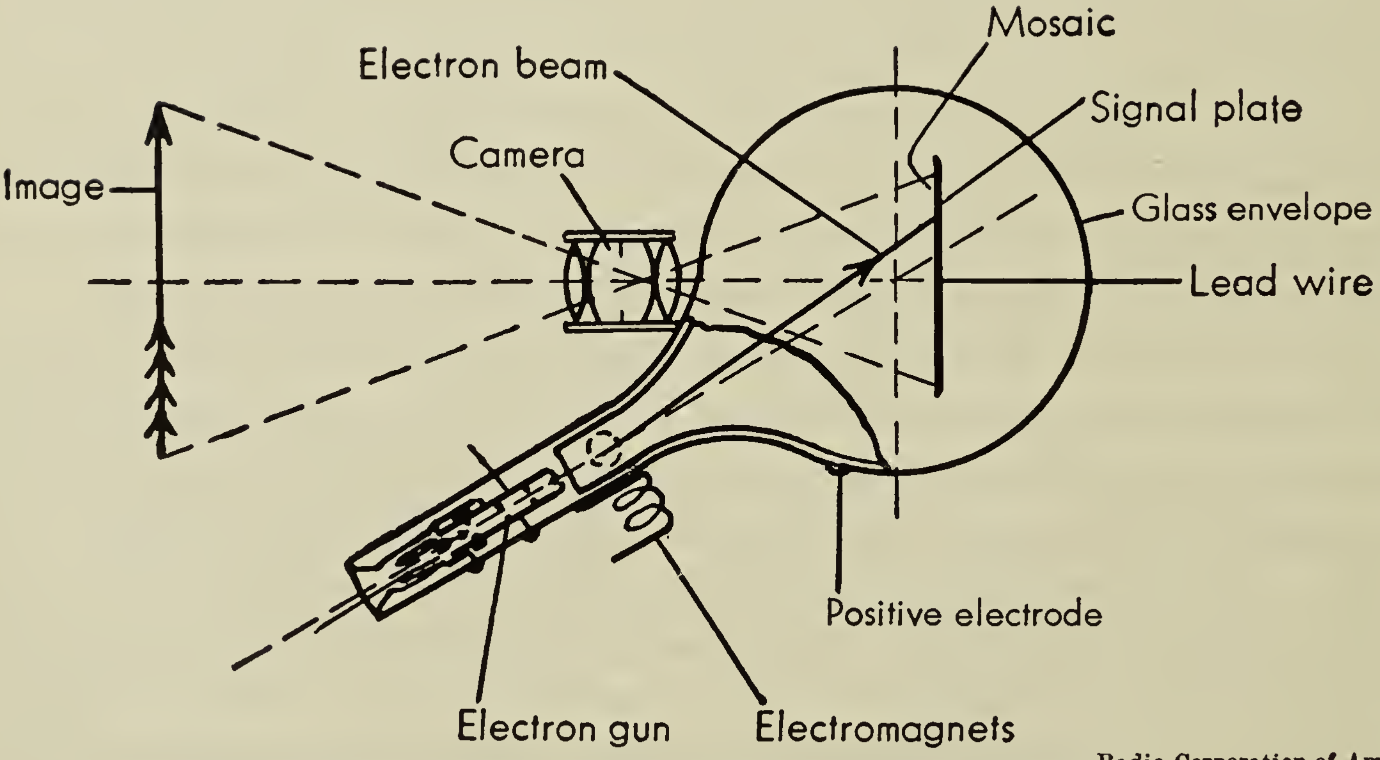
Since each one of these minute electric eyes which compose the mosaic is sensitive to the intensity of light rays which fall upon it, the degree of the positive electric charge which that tiny cell will carry at a particular instant depends on the intensity of the illumination which is reflected from the object being televised. Thus a cell which receives the reflected light from a well-illuminated point on the object will carry a proportionally strong charge; on the other hand, a neighboring cell which receives the light reflected from a shaded portion of the object will carry a commensurately weak charge. This relation holds for all the cells which are being light-excited at any moment throughout the whole mosaic. It now becomes evident that the light-sensitive side of the mosaic is nothing more than a device used to convert an optical image formed by the camera lens into a corresponding electrical image.

By an ingenious mechanism, to be more fully described later, this electrical image, or pattern, is resolved into a series of very rapid electric impulses. Moreover, the impulse coming from each minute photoelectric cell varies in magnitude, depending on the degree of light which excites that cell at the moment. These electric impulses are amplified and transmitted. The receiving set receives the television waves, and transforms them back into electric impulses similar to those sent out from the transmitting station. These impulses are in turn changed back into a series of light points of different intensity so related as to reproduce the image of the object being televised. The composite of light points which portrays the scene is reproduced so rapidly before the eye that it gives the impression of a continuous picture.



Radio Corporation of America

The iconoscope

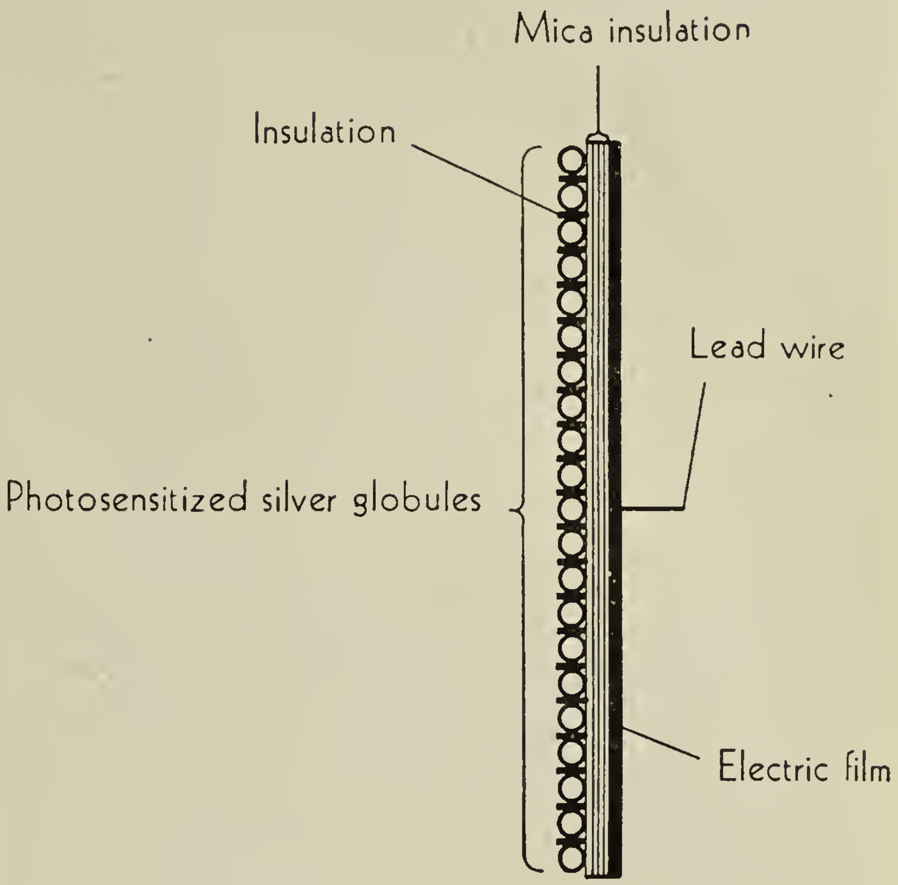


Mosaic
Electron beam
Signal plate
Camera
Image
Glass envelope
Lead wire
Positive electrode
Electron gun
Electromagnets

Radio Corporation of America

Diagram to show the principle of the iconoscope

The foregoing statements seem simple enough in themselves. But television, at its best, is very complicated, and we can attempt only to give the barest outline of the principles involved. In our description we shall endeavor to present the method perfected by Vladimir Zworykin and his associates.

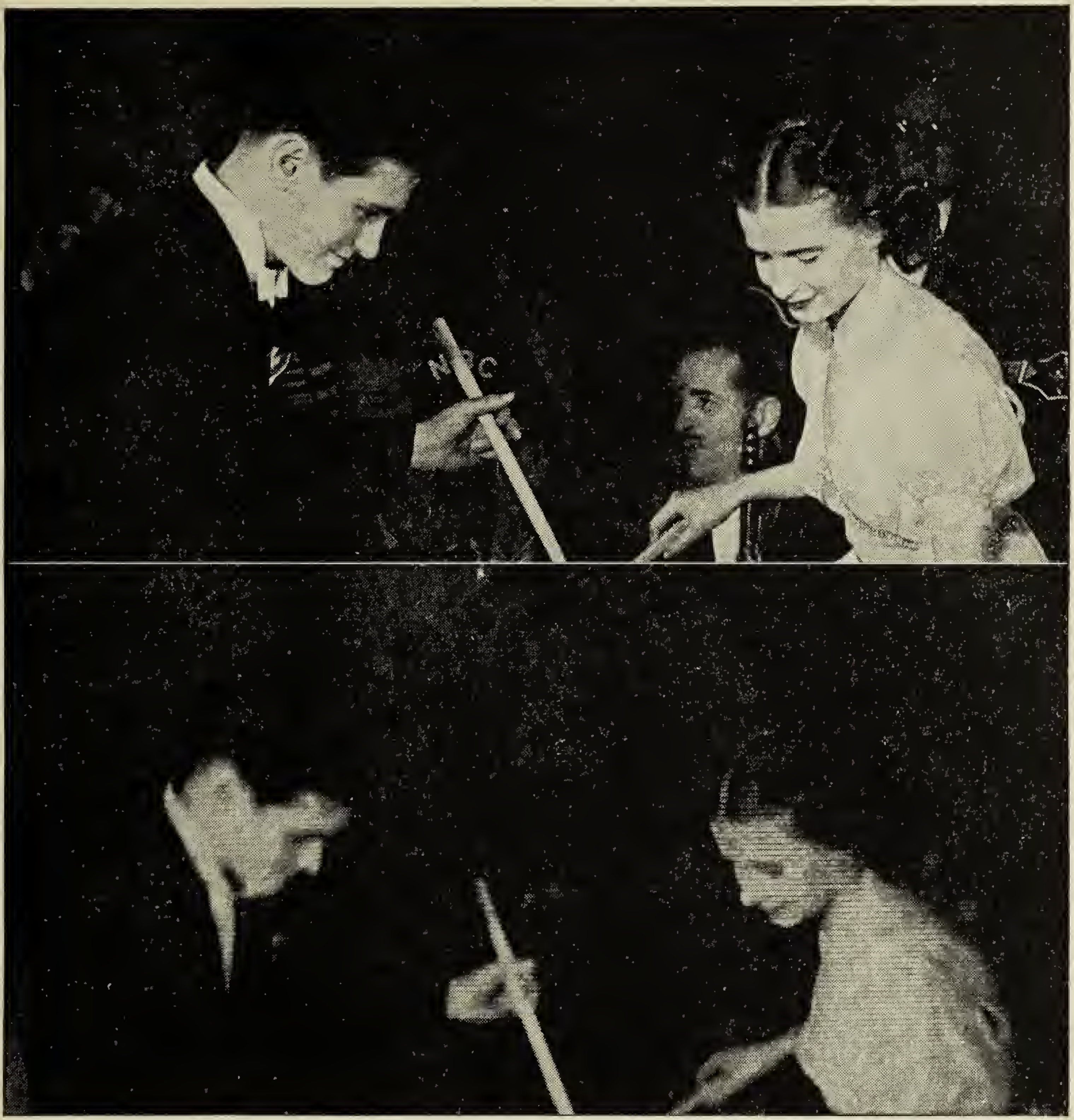


Edgewise view of mosaic

In this system the first step in the process occurs in the iconoscope (Greek *eikon*, "image" + *skopein*, "to view"), which converts a picture or scene image into electric impulses. Essentially the iconoscope consists of a powerful cathode (see figure on page 400), called an "electron gun," and a photosensitive mosaic plate in a highly evacuated glass envelope. The electron gun produces a fine pencil, or stream of electrons which is focused to a point on the mosaic. This electron beam can be made to move both horizontally and vertically and in this way scans the mosaic. The horizontal movements are effected by means of an electromagnetic field produced by a pair of platelike electromagnets. Vertical movement is produced by another pair of similar electromagnets, set a short distance ahead of the first and at right angles to them.

The mosaic (see illustration above) consists of a vast number, literally hundreds of thousands, of tiny *electrically isolated* photosensitized silver globules, the surface layer of which has been treated with caesium and oxygen. These globules, or minute photoelectric cells, cover the front side of a thin sheet of insulating mica. The rear side of the mica sheet is covered with an electric film. This film is the source of the induced electric impulses and is connected with a lead wire through which the electric impulses flow. The instant an image is thrown on the photosensitive side of the mosaic, the light rays throw the system of minute photoelectric cells into action. Each tiny cell emits electrons according to the intensity of the light which falls upon it. Cells situated in darker parts of the focused image emit a very feeble flow of electrons, while those located in better illuminated portions produce a commensurately heavy flow of these negative charges. The dislodged electrons are attracted away from the sensitive plate by a positive charge placed on another electrode, called the "positive electrode," which projects into the tube. The result is that the light-sensitive plate acquires a deficiency of negative electric charge, which corresponds, point for point, with the lights and shadows of the scene that is being televised. In other words, positive charges are distributed over the light-sensitive globules in this pattern. The longer the image of the scene continues to fall upon the plate, the greater the deficiency of electrons becomes. It is evident that by induction the electric film on the opposite side of the mica sheet takes on a negative charge of corresponding magnitude. The important function of the light-sensitive plate, it must be reiterated, is to transform the optical image formed by the lens of the camera into a corresponding electrical image and to hold this image until it can be dissected by the action of an electron beam into its component points.

At this juncture the electron gun comes into play. From it a very sharply defined stream of electrons is shot out, much as water issues from a nozzle under high pressure. This electron beam can be directed toward any point on the mosaic and is moved up and down vertically and back and forth horizontally by the action of the two pairs of magnetic poles. In other words, it is made to scan the picture image thrown on the mosaic by a lightning-like, sweeping, horizontal, back-and-forth motion. This motion is produced by the appropriately varied magnetic field. The beam begins at the upper left-hand corner, and when it reaches the right-hand side, it is automatically moved down to the next line below the one just traversed. This is accomplished by the other pair of properly timed, vertically acting electromagnets. The sweeping movement is continued until the entire mosaic is scanned. By this procedure each tiny photoelectric cell, as the electron beam passes over it, takes on the number of electrons which it needs to restore its electrical equilibrium. But as the positive charge on a particular cell is neutralized by the addition of electrons, this action also exerts a corresponding inductive effect on the electric film on the opposite side of the mica sheet. For now, with the positive charge on the light-sensitive face reduced, the surplus electrons, by repulsion, surge from the electric film out over the lead wire. In this way an electric impulse is produced. This impulse action is repeated for each photoelectric cell the instant the electron beam passes over it. It is also obvious that the magnitude of the impulse in each case will correspond to the electrical potential of the cell just before the beam passes over it. This means that for the brilliantly lighted cells the impulse will be stronger and for the less well-illuminated cells the impulse will be weaker. Any surplus



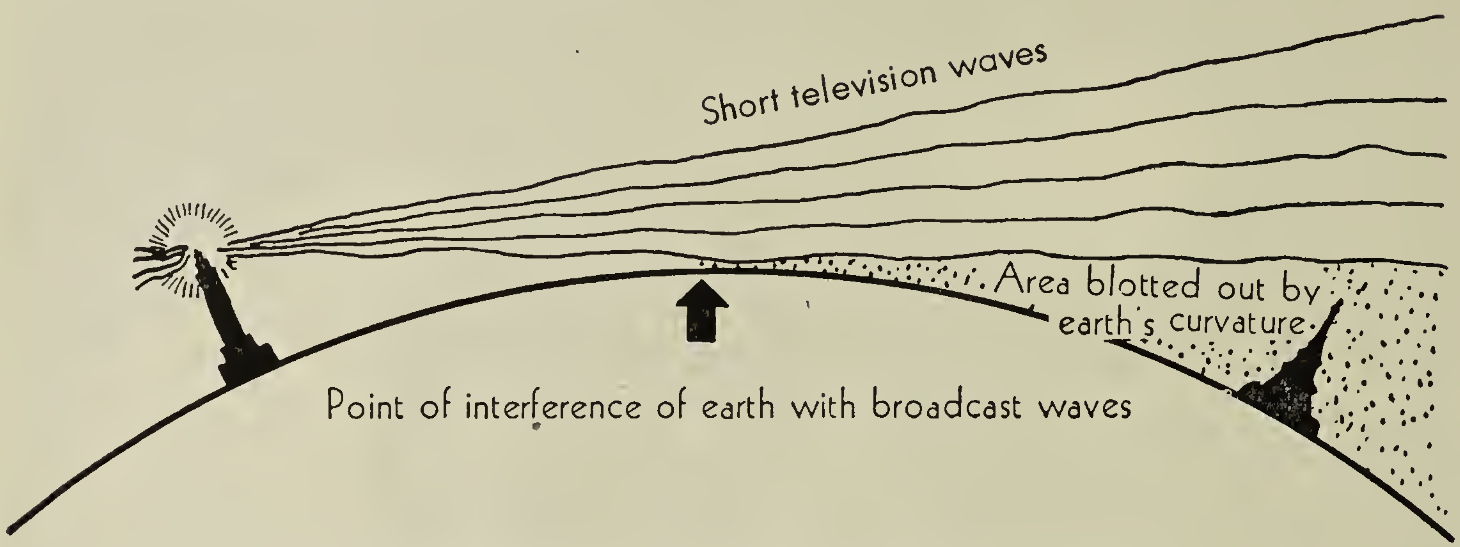
Morse-Pix, National Broadcasting Company

These pictures show the effect of television

The picture above gives the floor show as the photographer caught it; the one below, the same show as it appeared on the screen after it was televised

electrons resulting from the action of the electron gun diffuse off through the evacuated space in the tube to the positive electrode and are removed.

In this way the whole picture is resolved into a vast series of electric impulses which pass from the iconoscope out through the lead wire to the signal head. These impulses are modulated according to the lights and shades of the mosaic image and are comparable in every way to the electric impulses sent out in radiophotography from the microphone in ordinary radiobroadcasting. In fact, the radio engineers have dubbed the iconoscope the "ike" to correspond to the "mike."


Short television waves
Area blotted out by earth's curvature
Point of interference of earth with broadcast waves

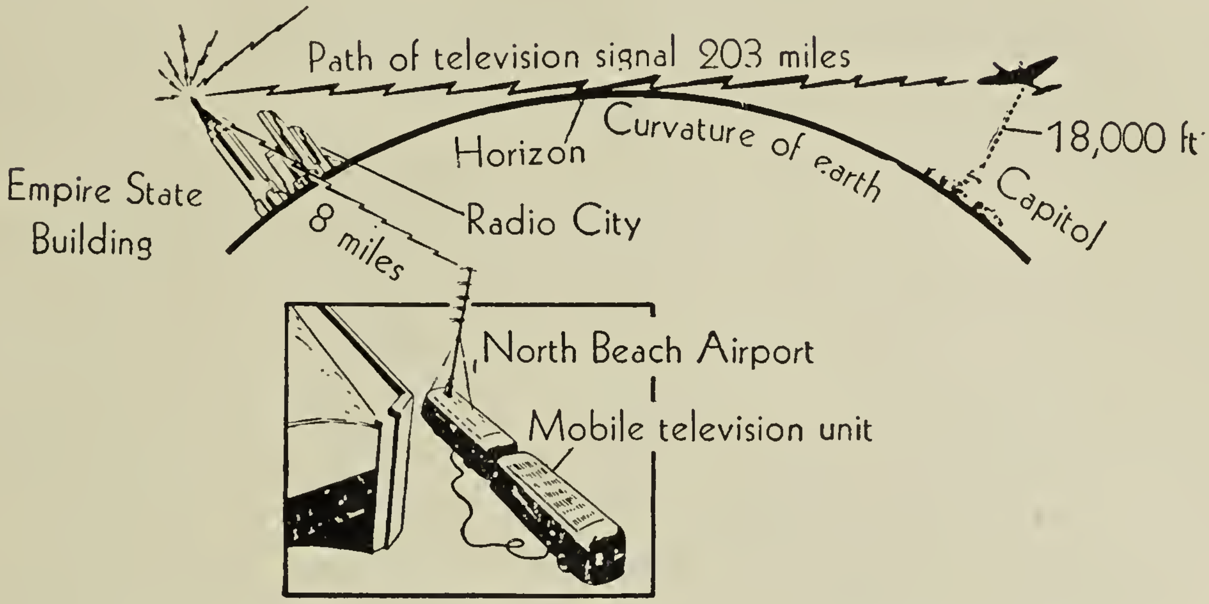
The curvature of the earth and television reception

Life

The scanning beam must move with tremendous speed. Indeed, it must move fast enough to give the eye of the observer, as he sees the scene reproduced on the screen at the receiving end, an impression not only of accurate composition but also of continuous vision. To accomplish this the scanning beam is made to sweep across the mosaic, which is about 4 by 5 inches in size, approximately 441 times at a single scanning. Since each line may be regarded as having about 500 photoelectric-cell points, each mosaic is composed of about 441 × 500, or 220,500, points, or picture elements. In regular motion pictures, about 30 frames, or separate pictures, are presented to the eye of the observer each second to give him the impression of continuous, unbroken movement. Likewise in television, to ensure apparent uninterrupted vision, about 30 different pictures or scannings must be made every second. All of which means that 30 × 220,500, or about 6,615,000, picture elements in the form of electric impulses must be transmitted each second. There are different scanning rates from these, but the one given may be taken as typical.

The Mosaic Impulses Are Broadcast by Radio. This stream of electric impulses delivered from the signal head of the iconoscope is now amplified and passed through a radio transmitting system and out to the antenna. From the antenna electromagnetic waves traverse space in all directions, just as ordinary sound radio waves do. In fact, these waves *are* very short radio waves.

When these incoming radio waves encounter the receiving aerial, they have been greatly weakened by their flight through space. Hence, after they are conducted to the receiver, they must be amplified several thousand times before the electric impulses which will reproduce the picture can be separated from the radio waves. Once separated, these impulses are again amplified about fifteen times before they are ready to be sent, not into a loud-speaker,



National Broadcasting Company

Experiment to show that interference by the earth blocks television waves

Through this experiment television waves were received over a distance of 203 miles

as in a radio receiving set, but into a special funnel-shaped glass bulb called a kinescope (Greek *kinein*, "to move" + *skopein*, "to view"). The kinescope receives the amplified electric impulses and by means of a second electron gun, similar to the one in the iconoscope, transforms them back into a properly modulated and accelerated stream of electrons. This electron beam is controlled in its scanning movements by two pairs of electromagnets set at right angles to each other, much as the electromagnets were in the iconoscope. The electron stream is thus made to scan a fluorescent screen each point of which glows when the electrons strike it. The screen consists of a luminescent layer applied to the inner surface of the larger end of the kinescope bulb. The fluorescent coating is usually prepared from a compound of zinc, oxygen, and silicon or sulfur.

The scanning beam in the kinescope is carefully synchronized (Greek *syn*, "together" + *chronos*, "time") with the one in the iconoscope, so that the instant an impulse is driven out through a photosensitive cell on the mosaic it is reproduced by the kinescope beam as a point of modulated light on the luminescent receiving screen. By this synchronized scanning the kinescope beam builds up an exact replica of the scene being televised.

The sound which accompanies many televised scenes is broadcast over a separate circuit, just as an ordinary radio program is sent out, the only difference being that the waves used are much shorter than those commonly employed. This sound also must be synchronized with the scanning beam of the receiving set; this is done after the manner in which sound is synchronized with the frames on a motion picture film.

Will Television Programs Be Available to the Public? This question is very difficult to answer. Television is carried on by very short waves, relatively speaking, which do not travel through distant space as radio waves do. Radio waves, as now sent by vertical antennae, are reflected back to the earth by the ionosphere and thus follow its curvature. Television waves do not do this. Being short, they travel outward in straight lines and are not reflected back toward the earth by the ionosphere, as the longer radio waves are. Those that go straight upward from the sending antennae and those at an angle to the earth's surface continue on, so far as is known, indefinitely. Those that travel parallel to the ground could be heard at great distances if it were not for the curvature of the earth. When they reach the horizon, they continue in a straight line, which soon carries them above the reach of any receiving set. Consequently the distance to which television broadcasts can be sent is only about from 40 to 50 miles. If very tall receiving antennae were used, reception could be had at greater distances. This was shown by an experiment carried on in connection with a New York sending station. Pictures were received at Washington, D.C., 203 miles away, by a receiving set carried up in an airplane to an altitude of 18,000 feet above the capital.

Under ordinary circumstances, for the reason just explained, the present transmitting area of a station is limited to a circle from 80 to 100 miles in diameter. This is true even when the broadcasting antenna is elevated to the top of the Empire State Building in New York City.

Whether this difficulty can be overcome in a practicable manner so as to make network television possible is still an unsettled question. It could be done through the use of a specially devised coaxial cable. By means of such a cable a program originating at a New York studio, for example, could be transmitted to a network of broadcasting stations throughout the country. This cable, however, is extremely expensive. An experimental one was put in between New York and Philadelphia some time ago. The cost was estimated at $5000 a mile, which makes it too costly for network television purposes.

Recently, after several years of experimentation, a new automatic radio relay device for use in television has been invented. This device consists of a rather small receiver and transmitter, all in one, which works without the attention of human operators. These relays can be mounted on steel towers

National Broadcasting Company

Mobile television station

100 feet high and spaced from 20 to 50 miles apart. It is believed that a line of them could be used to effect network television broadcasting instead of the very expensive coaxial cable. Indications, then, are rather favorable that in the future networks will be established which at least will cover the more densely populated areas of the country.

The present size of the reproduced televised scene presents an obstacle to the widespread use of television. Receivers commercially available today produce pictures ranging in size from 3 by 4 inches to approximately 8 by 10½ inches. This limits television to a small group of observers, since for even the larger-sized screen the best viewing distance is but three or four feet. Larger pictures can and have been made which may be viewed at a distance of seven or eight feet, but the necessary equipment is not suitable for the home because of its cost and technical complexity.

Another difficulty is the present cost of television equipment and program-broadcasting. To date television is still in the experimental stage; yet millions of dollars have been expended on research in this field. One leading American company alone has spent $9,250,000, and it has been estimated that the total experimental cost to European and American companies to date has exceeded $20,000,000. For actual equipment it has been found that each television station has to spend at least $250,000, or about ten times more than for radiobroadcasting.

The programs, likewise, far exceed the cost of radio programs. If continuous programs are to be produced, acres of ground must be given over to rehearsing coming productions, and an army of artisans must be kept busy preparing scenery for the different sets. An expenditure of $10,000 a minute for the actual showing time of dramatic reproductions is about the average. At this rate a studio which plans to give only one new play, an hour and a half long each day, must reckon with a daily expenditure of $900,000 for this purpose alone. It is hoped that this cost can be brought down eventually to about $500 a minute.

One broadcasting company has fitted out two ten-ton trucks with $100,000 worth of television equipment. One of them contains the iconoscope and the necessary paraphernalia for scanning. The other contains the broadcasting equipment. These portable units are designed to make possible the broadcasting of outdoor events which cannot be taken into the studio.

General television broadcasting, then, is for the present limited to the populous centers. How soon it will become general no one knows. A discovery may be made at any time which may render it as widespread as radiobroadcasting is now. Unless this happens, however, it is believed that it may take several years of slow, steady, technological progress to make television available to the general public. Indeed, for the more sparsely settled areas, service of this kind may never be established.

Questions for Study

1. How are the transmission and reception of radio waves accomplished?
2. How does the electric eye function?
3. How do modern radio receiving sets differ from pioneer sets?
4. How does the particular device in a radio set work to make possible the reception of broadcasts of different wave lengths?
5. How is it possible to send a picture of an event to a distant point without sending the printed picture?
6. What are the important scientific principles which are brought into play through the agency of the vacuum tube?
7. How does the vacuum tube function as a fundamental part of every radio?
8. How do the transmission and reception of radio waves tend to prove the wave theory of radiant energy?
9. How many uses can you mention for the modern photoelectric cell?

10. How is the photoelectric cell used to control the lighting in a private or public room?

11. How is the sound produced that accompanies the picture in a modern motion-picture show?

12. What are the basic principles underlying present television broadcasting and reception?

13. How would you explain the fact that the maximum distance at which televised programs can be picked up by receiving sets is about 50 miles?

14. When radio programs are broadcast over the nation by a network system, how are they sent from the central studio to the various broadcasting centers?

15. Why has it taken so long to develop television when radio has been an accomplished fact for many years?

16. How does radio affect international relations?

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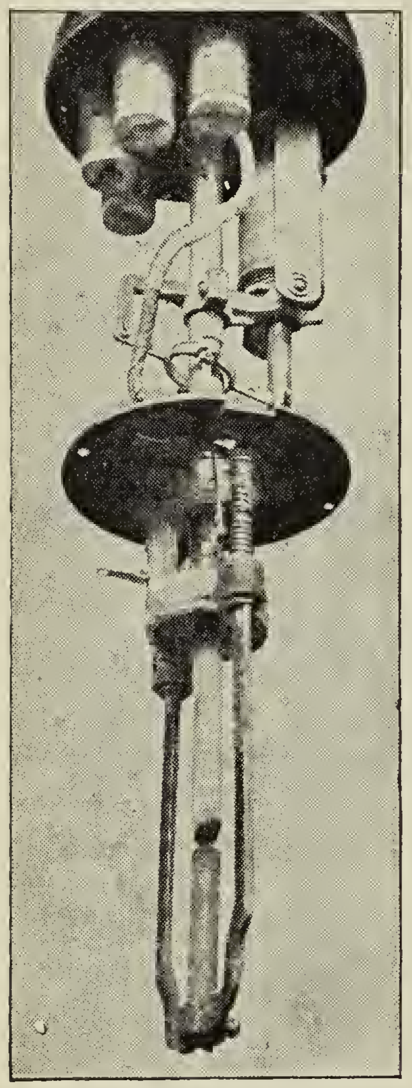
CHAPTER TWENTY-THREE

Electrical Energy and Radiant Energy Have Made Possible the Electric Light and the Airplane

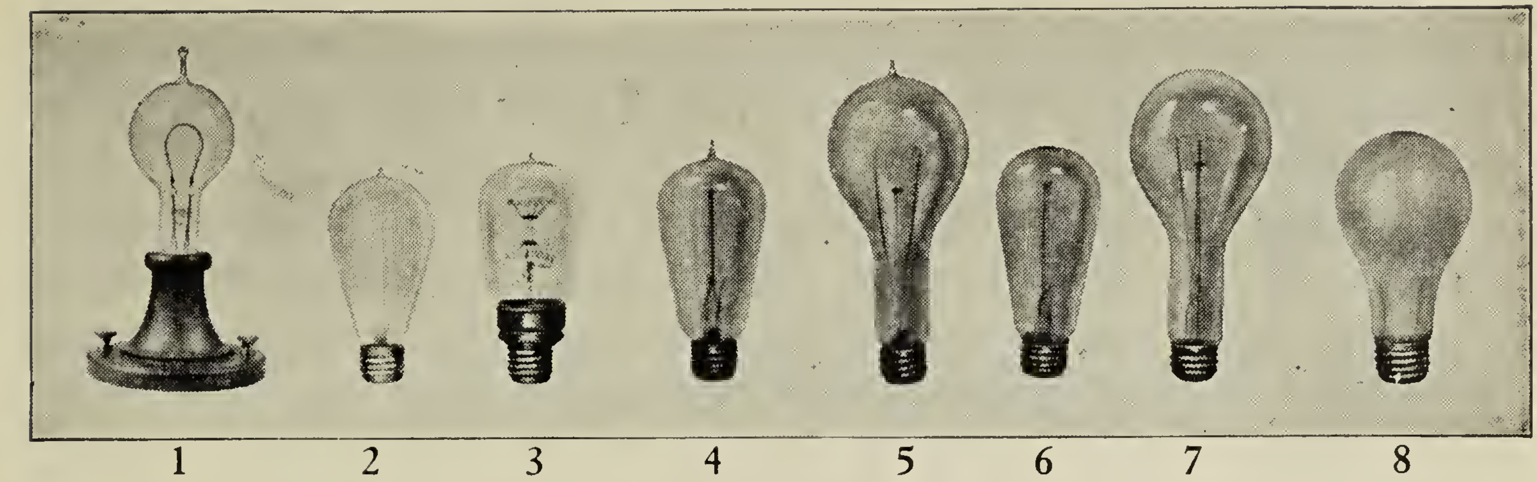
The Incandescent Light Is Indispensable in Modern Life. After electricity was generated on a commercial scale, the first artificial light to come into general use was the carbon arc lamp. In this light the illumination resulted from the passage of the current between the closely adjacent ends of two vertical sticks of carbon. This lamp threw out a powerful light, but, because of the slow combustion of the carbon, which varied the length of the arc gap, its intensity varied noticeably. Moreover, the carbon arc light was an inconvenient one because each day it had to be lowered to the ground and the carbon replaced by hand. In addition, its intense light and its mechanism did not adapt the carbon arc to the needs of offices, small shops, and private homes. As a result of these disadvantages Thomas Edison, soon after entering the field of practical electricity, began to work on an incandescent light that would fulfill these needs. By many electrical scientists this feat was regarded as impossible.



An early type of carbon arc lamp

Edison's chief difficulty was encountered in getting a filament with such resistant qualities that the current, in passing through it, would heat it to the glowing point and yet not burn it out. Since he knew that such a filament would require a substance with a high melting point, he tried carbon. His first lamp was a charred strip of paper mounted in a glass vessel from which most of the air had been removed with a vacuum pump. This light burned out in eight minutes. In 1879, however, after many discouraging attempts he succeeded in producing a filament from a cotton thread that glowed for forty consecutive hours. This was the first practical electric light, and the results convinced Edison that an incandescent lamp for popular use was quite within the range of possibility.

Up to this point Edison had spent $40,000 on his experimental results.



General Electric Company

Incandescent lamps from the first to the present

1, Edison's first lamp; 2, carbon-filament lamp; 3, tantalum-filament lamp; 4, drawn-wire filament lamp; 5, gas-filled lamp; 6, vacuum lamp; 7, gas-filled lamp; 8, inside-frosted lamp

His chief difficulty still was in finding a sufficiently durable carbon filament. To this end he dispatched assistants to the ends of the earth. He sent men to Peru, Brazil, China, Japan, India, and several other countries. He tested no fewer than six thousand vegetable products. In the end it cost him $100,000 to discover that the Japanese bamboo produced the best fiber for making a carbon filament.

Chiefly because lamps with carbon filaments possess poor lighting qualities and are expensive to operate, D. W. Coolidge, an associate of Edison's, tried tungsten. This metal in its natural state is as brittle as glass. After years of experimentation Coolidge succeeded in perfecting a process by which tungsten molecules could be pressed together to form a tough, fibrous structure which could be fashioned into a thin wire of uniform size that lent itself admirably to incandescent-lamp-making.

The effect of this advance on electric illumination was startling. The carbon filament gave a light that was yellow. The new tungsten filament produced a brilliant white light. In addition, it consumed only one-half as much electricity per candle power.

Another disadvantage of the early electric lamps was that the carbon was volatilized by the heat. Producers could not keep the highly heated filament from slowly "evaporating" and becoming deposited as a dark coat on the inside of the bulb. The same effect could be observed in the tungsten lamps. This loss both weakened the filament and cut down the efficiency of the light. Langmuir found that by filling the tungsten lamp bulb with some gas which would not combine chemically with the filament he could put the filament under a pressure that would reduce this slow evaporation. Argon could be used, but it is relatively scarce. Finally he found nitrogen to be suitable, and thus the highly efficient nitrogen-filled tungsten lights in use today were perfected. The tungsten filament with the nitrogen-filled bulb form a light which gives just about three times as much light for the same money as the old carbon filament gave.

A hundred and fifty years ago the average candle-lighted home consumed approximately five candles per evening. The light produced amounted to about fifteen candle hours. Today the average home may have one thousand candle hours of clean, convenient illumination for the price of four smoky tallow tapers.

New Types of Arc Lamps Have Been Developed. We have already mentioned the inconveniences and undesirable features of the old-fashioned carbon arc light. Within recent years, however, a new type of arc light is being introduced with great success. Lamps of this type use either a mercury-vapor or a sodium-vapor arc. The light from the mercury lamp has a greenish-blue tinge. But each 400-watt mercury light is combined with a 200-watt ordinary incandescent lamp, whose light, as everyone has observed, has a yellowish hue. The two lights, when blended, are almost white, thus simulating daylight and being especially desirable for street-lighting. A unit, or "luminaire" as lighting engineers call the above-described combination, is about eight times as efficient in illuminating power as an ordinary incandescent bulb of comparable size. A 200-watt mercury light which is interspersed with the common tungsten bulbs has recently been developed for use in industrial plants, stores, and buildings of similar size. Its effect is said to be almost like daylight.

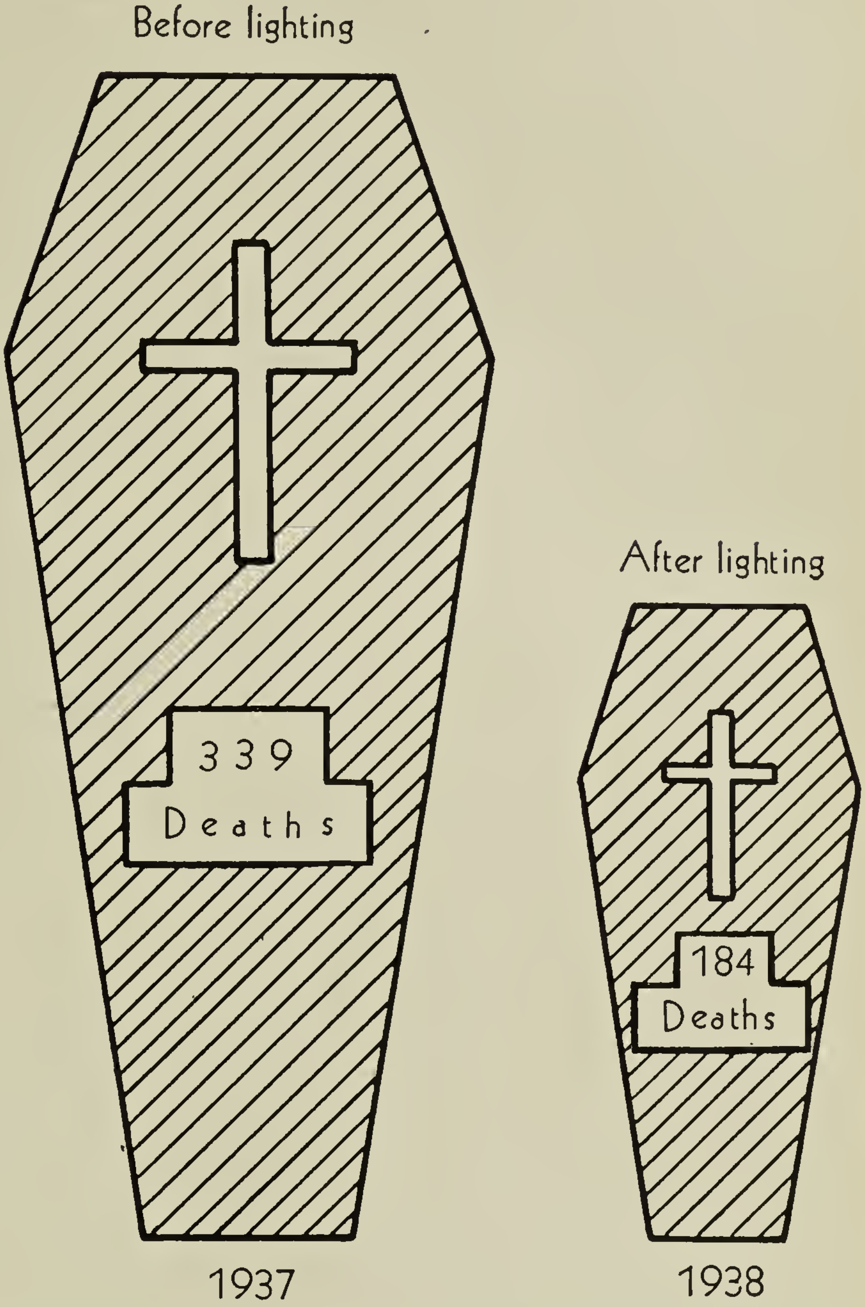
The sodium-vapor light closely resembles in principle the mercury-arc light except that sodium is used to form the arc instead of mercury. This lamp gives a soft yellow light which eliminates glare and thus enables automobile-drivers to distinguish even small objects much more distinctly than is possible by the light of the common incandescent lamp. In many cities sodium-vapor lamps are now being installed to illuminate boulevards, and in the more populous districts they are being tried out as a means of lighting the highways. They operate at a cost just about one half that of the ordinary light for the same illumination.

St. Paul Boulevard in Rochester, New York, is illuminated with sodium-vapor lamps. In the year following their installation the number of accidents was cut to one third that of the previous year, and not a single pedestrian was struck.

In 1938 in New Jersey 16 counties and 145 municipalities co-operated with the state in giving this new type of illumination a trial on highways. Although along some roads the lights were not installed until midyear or later, the loss of life at *night* by traffic accidents over these roads was cut from

339 to 184 deaths, or 46 per cent, as compared with the fatalities of the previous year, while during the same period the loss of life in *daytime* was reduced but 10 per cent. At the same time, the 145 cities by installing the improved illumination and controls cut the cost of their light bill $76,804.

Sodium-vapor lights are installed throughout the famous San Francisco–Oakland Bridge. Their cost of operation is less than one half that of the common light of equal intensity, and it is said that more than thirty-five full moons would have to shine simultaneously to give the same average illumination effects. Mercury-vapor or sodium-vapor lights are largely replacing the large incandescent filament lamps in street and highway illumination today.

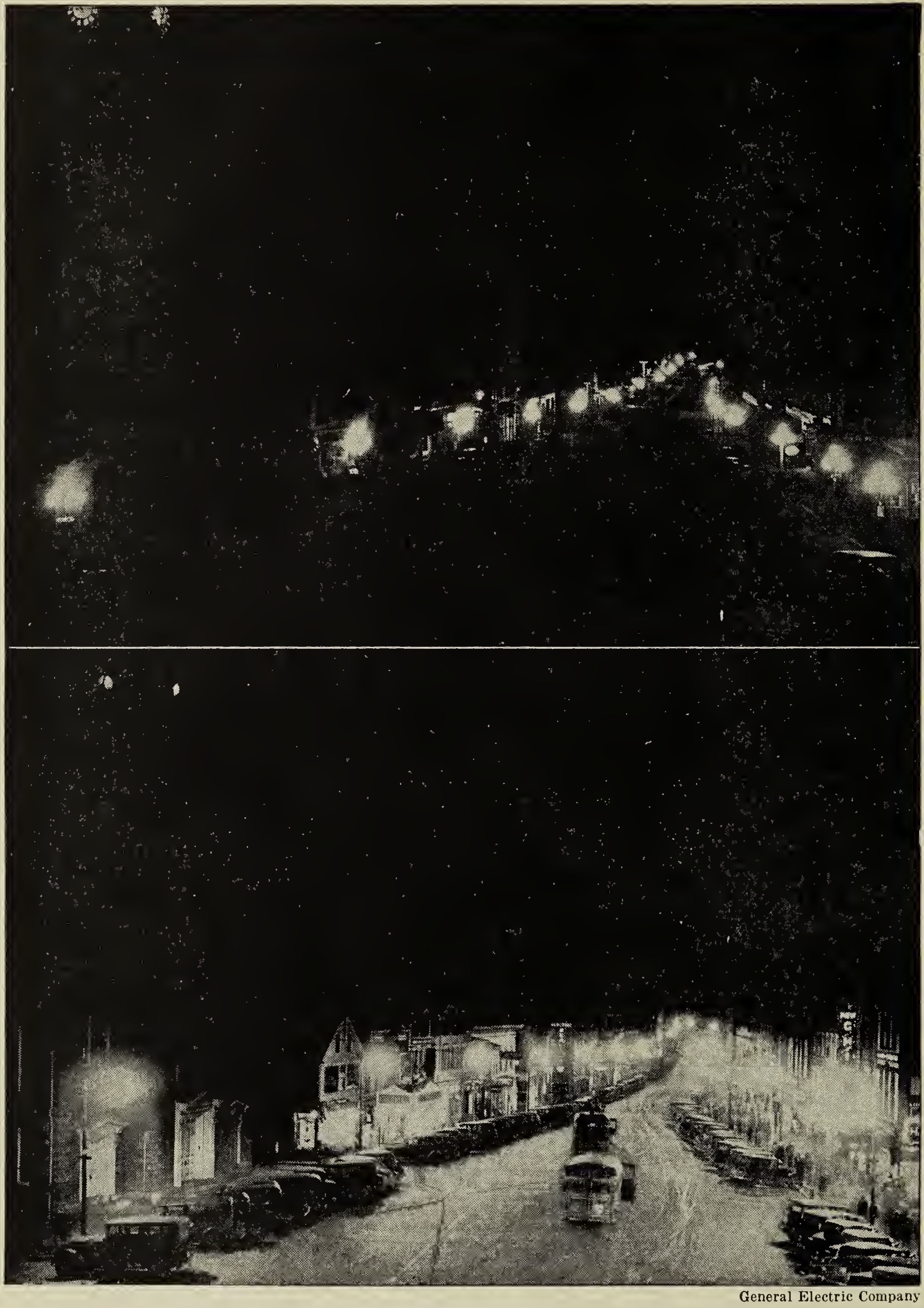


New Jersey State Highway Department

The lighting of highways in sixteen New Jersey counties resulted in a reduction of deaths of more than 46 per cent

A New Fluorescent Lamp Has Recently Been Produced. We have found in a previous chapter that many ordinary-looking nonluminous minerals when excited with ultraviolet rays emit a vivid, bright, beautiful light of varied color, depending on the chemical composition of the mineral (see page 368). This principle is employed in the new fluorescent lamp.

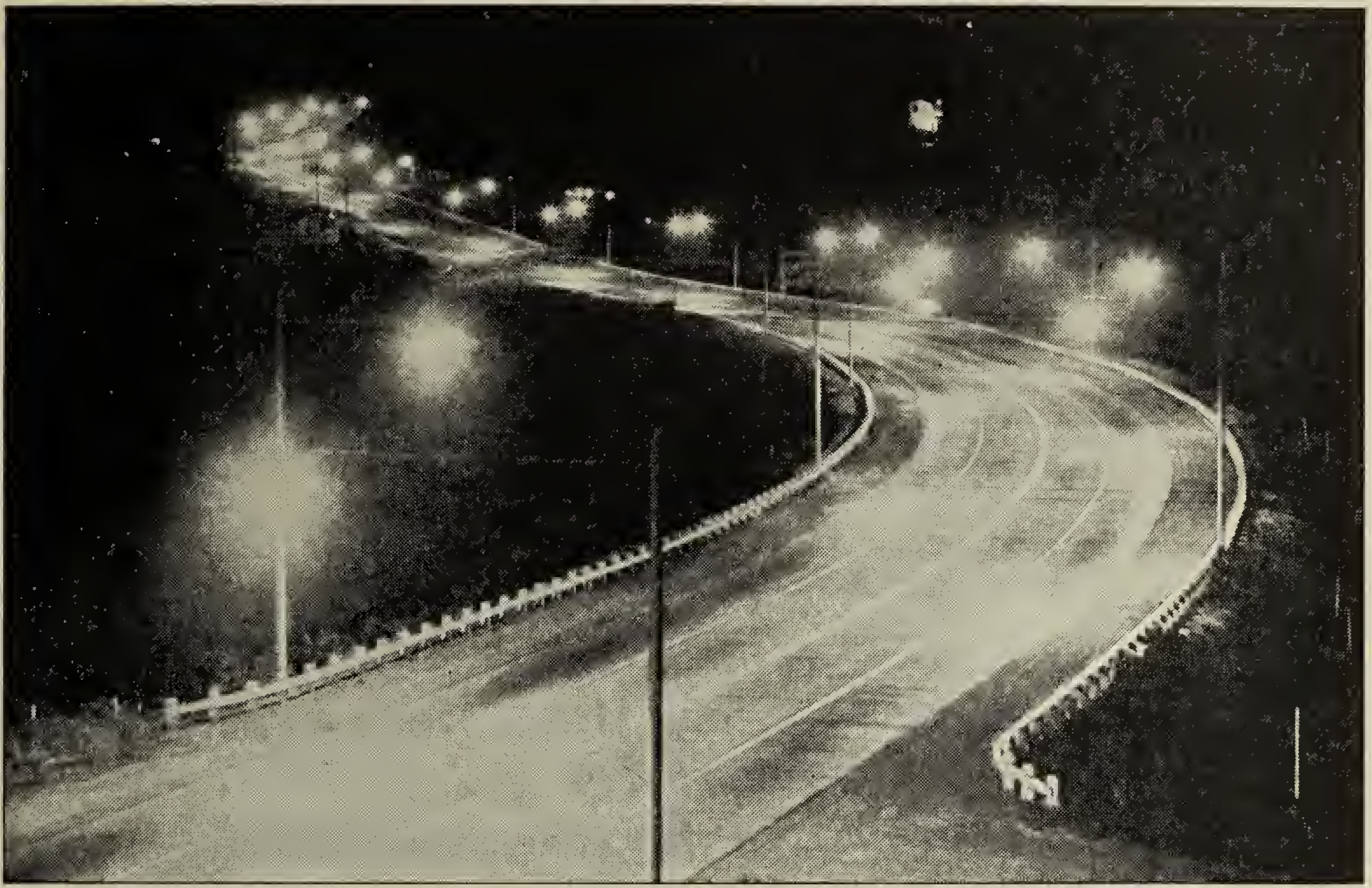
Essentially the new fluorescent lamp consists of a glass tube of from one to one and a half inches in diameter through the center of which extends a mercury arc. This arc produces a large quantity of fairly short, ultraviolet, invisible radiations. The walls of the tube on the inside are coated with fluorescent powders, which when excited by the ultraviolet rays emit a beautiful characteristic glow over practically the whole inner wall of the tube. The tubes now being made range in length from eighteen to thirty-six inches.



General Electric Company

Street lighting

Above, a business street before the installation of mercury incandescent lamps; below, the same street after installing mercury lamps



General Electric Company

Bay View Highway, near San Francisco, illuminated by sodium-vapor lamps

This type of lamp is from three to two hundred times as efficient in light output as the ordinary incandescent light and produces less than 50 per cent as much radiant heat.

The special bulb developed for these lamps gives a light "almost perfectly matched to standard daylight," and "colored objects are seen in all the vividness of their outdoor appearance." Consequently, as dry-goods and clothing stores are equipped with this type of illumination, shoppers do not have the experience of buying an article which is highly pleasing when examined by artificial light but disappointing when viewed by daylight.

A small-capacity fluorescent lamp is now being used as a reading lamp and to illuminate Pullman berths, cabins on air liners, closets, mirrors, and portraits in the home.

A new lamp is still in the experimental stage. It is a germ-killing, ultraviolet lamp which produces waves most of which are of 2537 angstrom[1] units—the length at which radiations are most germicidal in their effect. Present research indicates that a 15-watt lamp of this kind under proper conditions can sterilize 200 cubic feet of air per minute. The lamp which produces the lethal rays is a tube of special glass, filled with mercury vapor at low pressure. It resembles the fluorescent lamps, except that there is no fluorescent coating inside the tube. When supplied with the necessary auxiliary equipment, it will operate on the ordinary 110-volt electric current, and the largest size now being made is one inch in diameter and eighteen inches long.

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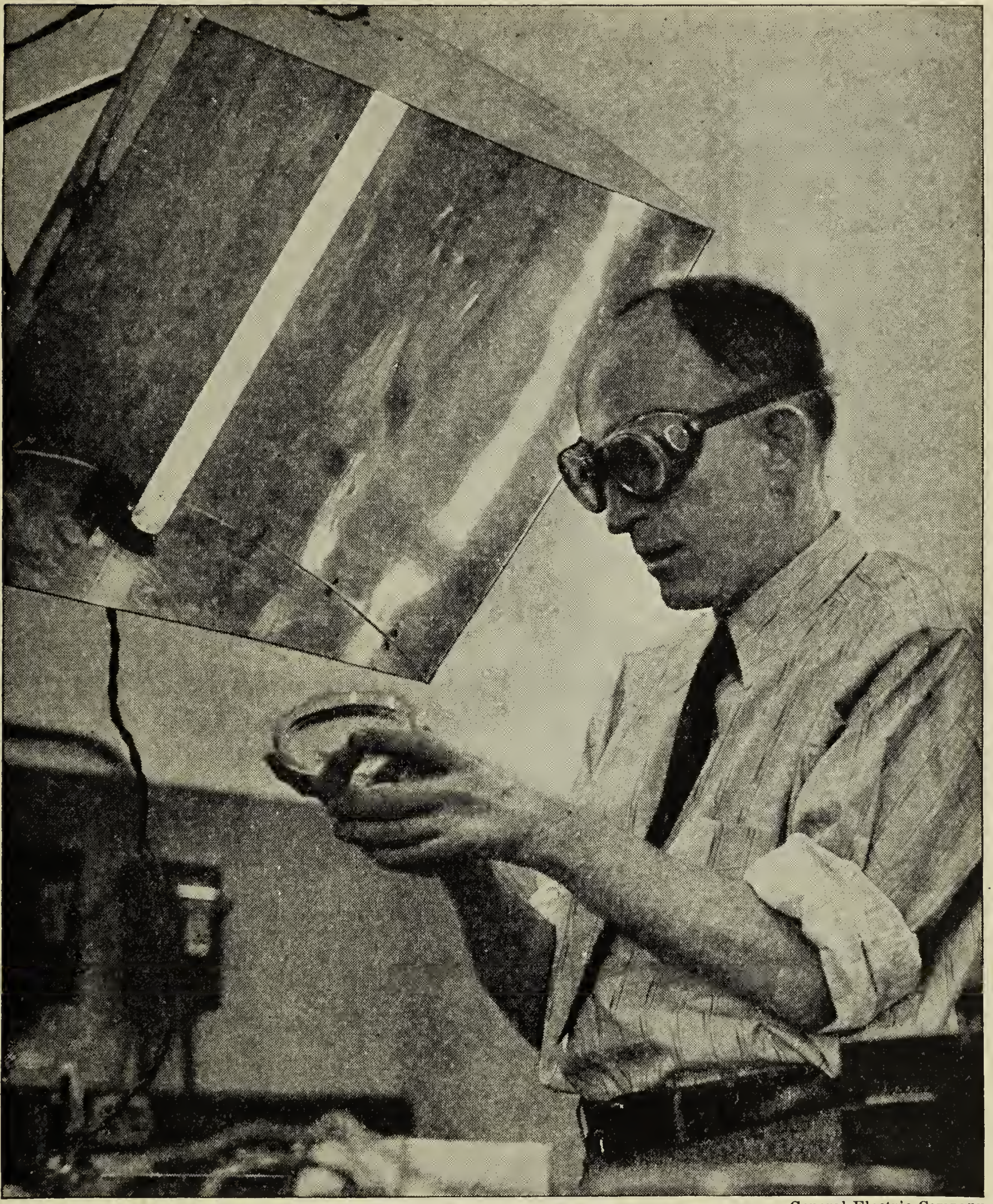
[1] An angstrom unit has a value of $\frac{1}{10,000,000}$ of a millimeter.

Several hospitals are experimenting with this new ultraviolet lamp as an agent to kill pathogenic microorganisms in circulating air (see figure on page 417). They are also testing its effectiveness as a curtain of germ-killing light across the entrance of the rooms of patients who need to be protected from microorganisms that might be carried in currents of air. "In the latter application, a row of the lamps is installed above the doorway. Reflectors cast the invisible rays straight downward toward the floor and a 'curtain of death' is created for any air-borne bacteria entering or leaving the protected room."

"Other possible uses being tested for the lamp include sterilization in cosmetic manufacture and in food industries, particularly meat storage, bakeries, and canning. The lamp may supplement present sterilization methods used in restaurants, soda fountains, and bars to furnish bacteria-free glasses. It may also prove useful in keeping sterile articles which have already been sterilized, such as hospital bandages and dental instruments." Another suggested possibility is the radiation of air in surgical operating rooms to protect the incision from possible infection. Certain of the new-type electric refrigerators for home use are equipped with this light. Manufacturers assert that the emitted rays have great value in keeping the food sterile, thereby preventing fermentation and spoilage. A new fluorescent-lamp factory at Fairmont, West Virginia, designed to turn out a hundred lamps a minute, is equipped with white-light (similar to daylight) bulbs throughout and is air-conditioned. "A battery of more than one hundred 'sterilamps' stands guard in the air-conditioning system." The battery radiates invisible ultraviolet rays that kill about 95 per cent of the bacteria in the air as it passes through the ducts.

The Airplane Is an Important Means of Transportation. Airplanes are driven by internal-combustion motors, and the energy employed in these engines is heat. From the viewpoint of the motor power employed, then, aviation might have been considered in connection with heat as a form of energy. However, a very great deal, if not most, of the energy used in the directing and control of airplanes, both from the ground and in the air, is either electrical or radiant. For this reason many of the principles underlying airplane operation could not be understood until after energy in these forms had been considered. Hence it seemed permissible to defer consideration of the airplane until the basic aspects of these forms of energy had been studied.

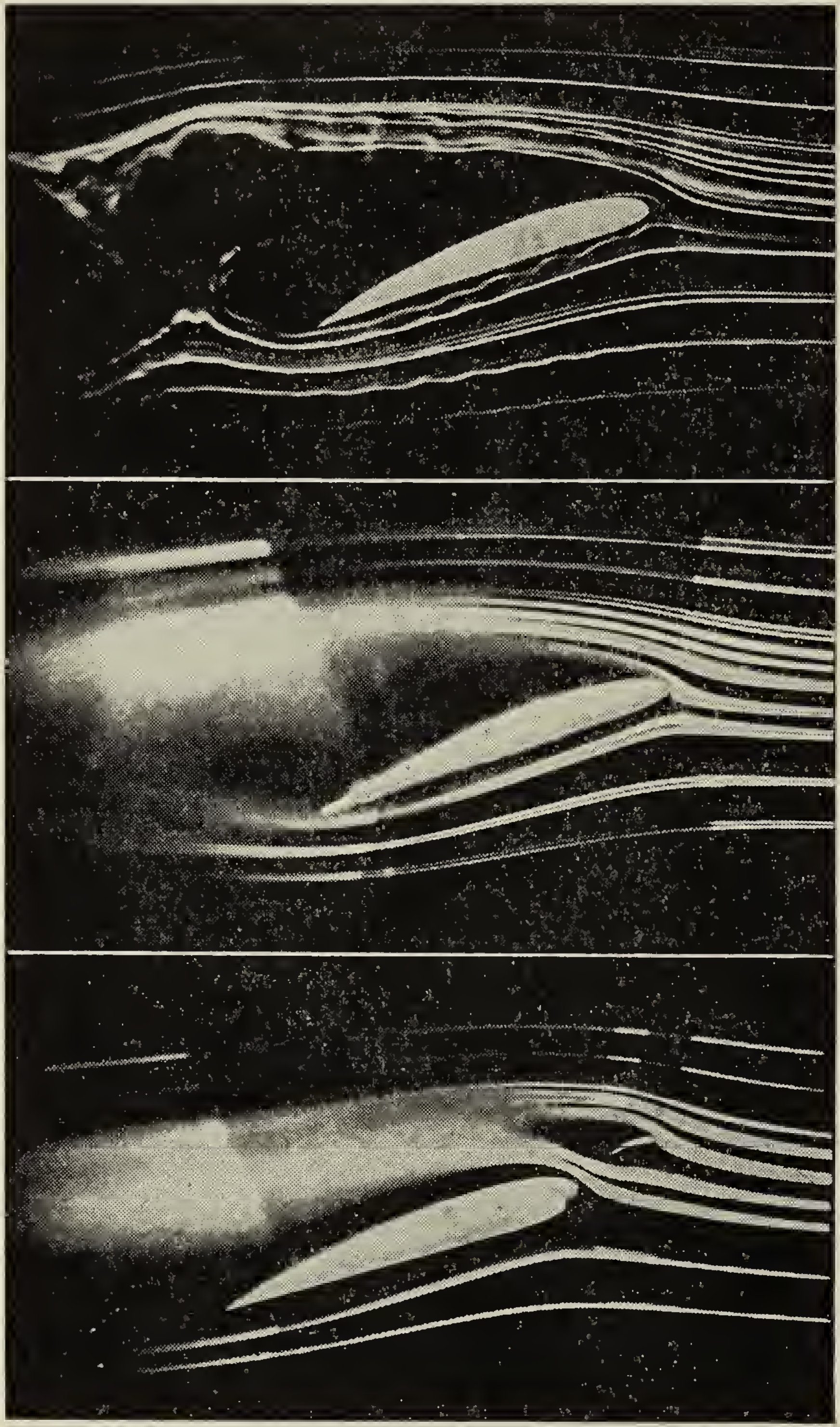
For some time before December, 1903, two brothers, Wilbur and Orville



General Electric Company

The new germicidal lamp

Wright, had been experimenting with gliders along an isolated part of the beach near Kitty Hawk, North Carolina. Encouraged by their success, they decided to build a heavier machine and to attempt to drive it with a gasoline motor. The Wrights had profited by a few suggestions obtained from earlier attempts at airplane construction; so, supplementing these with their own ideas gained from building and operating gliders, they proceeded to fashion their first machine. As compared with present-day models, their initial airplane was a crude and clumsy affair. Nevertheless, in essential features, it embodied the same principles employed today in airplane construction.



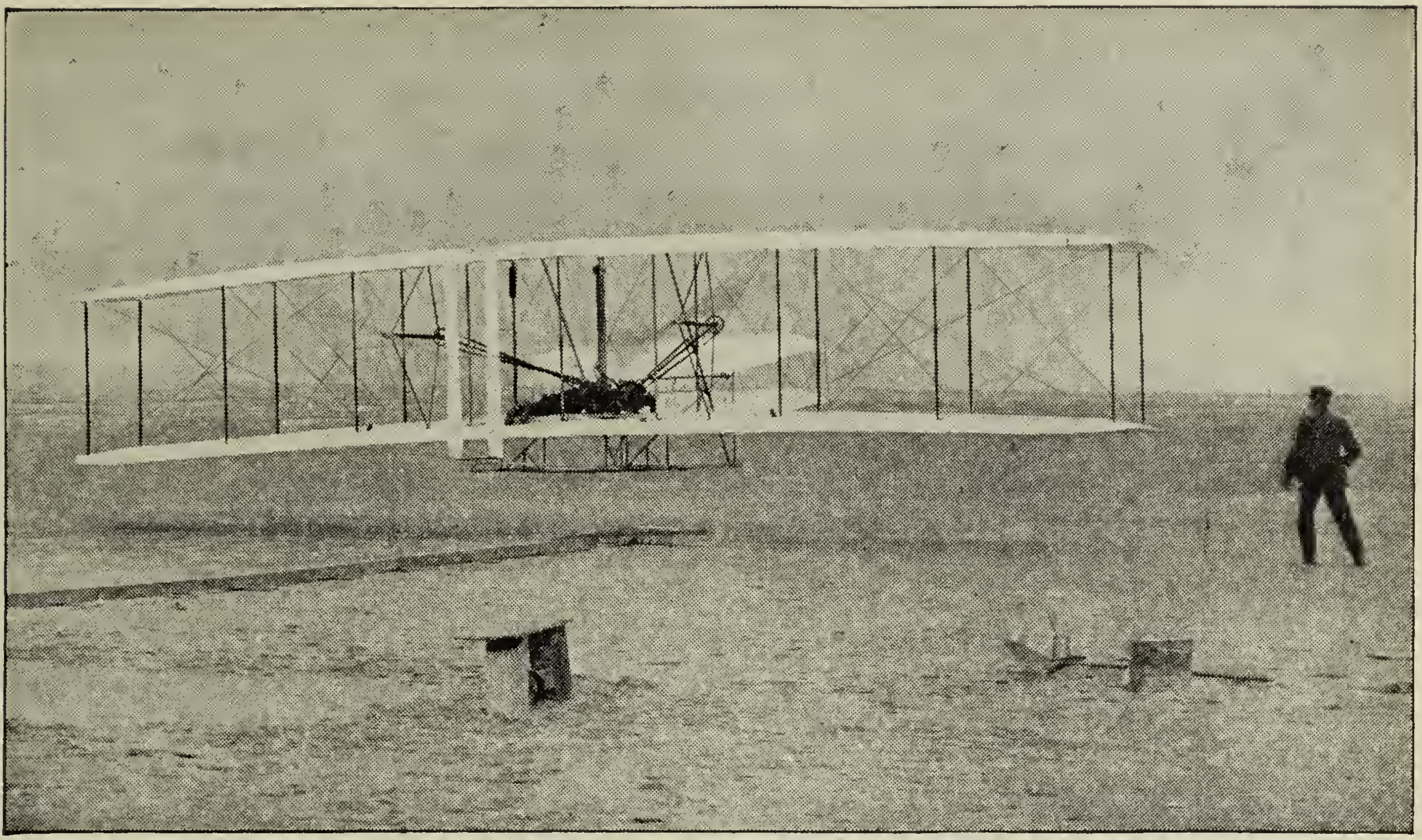
National Advisory Committee for Aeronautics

Air flow around wing

The flow of smoke streamers over a model of an airplane wing shows how the air exerts lifting force. The use of new material on the wing (auxiliary airfoil) improves the character of the air flow

Mechanically it was to be supported in the atmosphere by rigid biplane wings pushed rapidly against the resisting air by the force of a motor-driven propeller placed at the rear. The wings were set at a slightly uptilted angle when viewed from the front and received their buoyant action from atmospheric pressure against the undersurface of the wing. As the plane moved forward, the undersurface of the wing, owing to its shape, pressed downward on the air and thus tended to compress it. This in turn, because of the elasticity of the air, gave the wing, and hence the whole airplane, a strong upward thrust. Likewise, because of the shape and angle of the wing, rapid forward motion produced by the pull of the swiftly revolving propeller caused the air to flow over the top of the wing in such a manner as to create an area of reduced pressure, which made the upward thrust of the air from below more effective.

The clumsy steering device was placed at the front end. Instead of a wheeled undercarriage to support it, the plane had two skids resembling sled-runners. Consequently a launching device had to be used to start the machine on its flight.



The Wrights' first flight

On the morning of December 17, 1903, everything was in readiness, and by tossing a coin Orville was delegated to make the initial flight. As the motor roared, the plane moved forward, slowly at first, with Wilbur keeping pace by running along on the ground. Gradually it gained elevation and was kept aloft 12 seconds, during which it reached an altitude of 120 feet. Three further flights were made that same day, the last of which was for a duration of 59 seconds, with the plane traveling a distance of 852 feet.

In the light of today's achievements in the air, these first flights were certainly not imposing. Nevertheless this was the first time that flight in a heavier-than-air machine had been successfully achieved. For this reason history was made that day, and it was perfectly fitting that the United States government, in 1932, should erect a monument in honor of Orville and Wilbur Wright. The monument stands on the site of the first flight at Kitty Hawk.

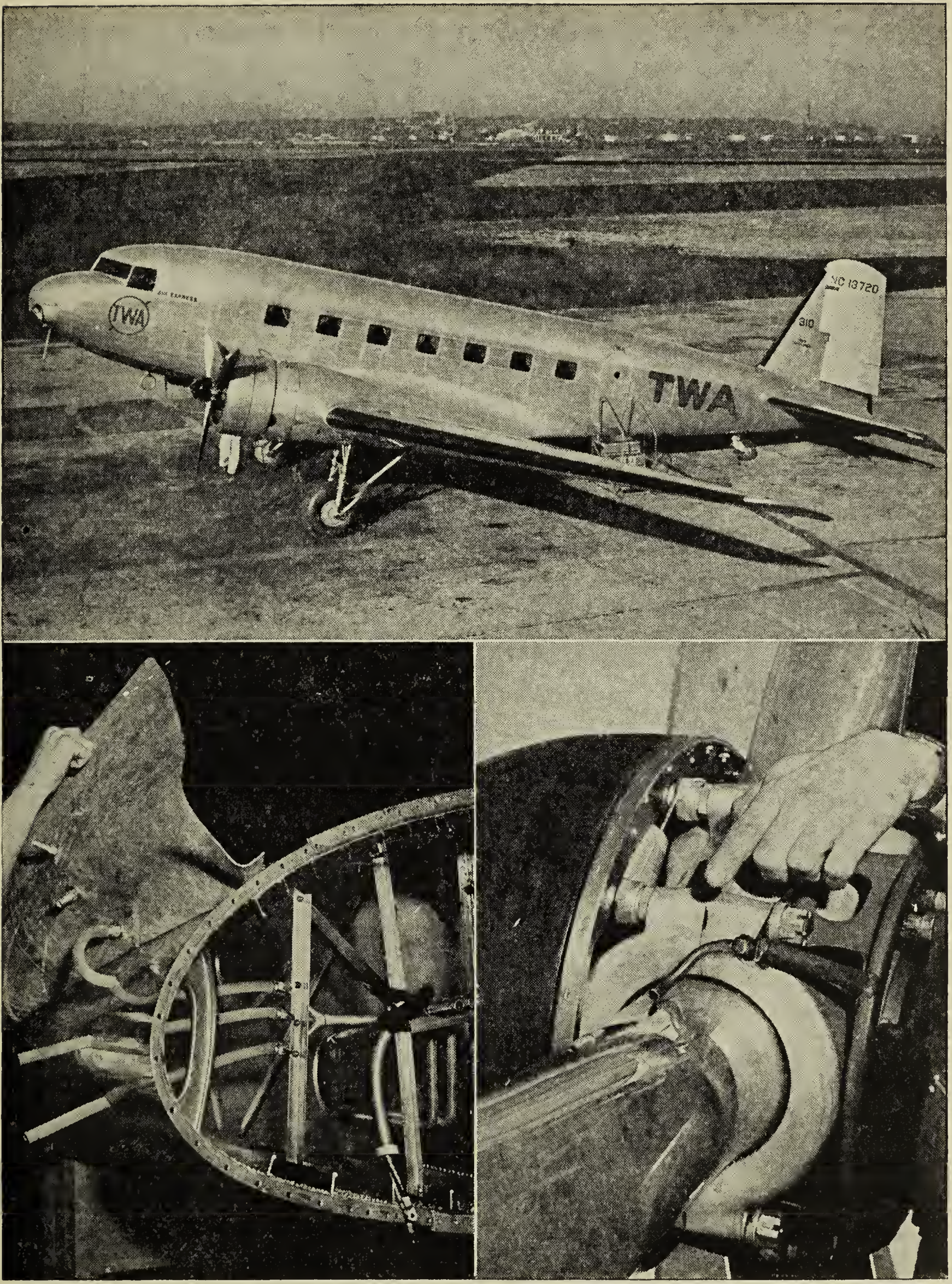
Advances Have Been Made in Airplane Construction and Operation. Since 1903 airplane construction has developed rapidly. The extensive use of these heavier-than-air machines during the first World War for observation, pursuit, and bombing furnished a potent added stimulus. During and since that war advances of many kinds have been introduced. These, to mention but a few, have included better designs, more powerful motor units, much larger models, reduced weight through the use of alloys, ship-to-ground communication by radio, directing beams to assist when flying visibility is low, and automatic steering devices. Despite all these advances, however, the fundamental principles underlying airplane construction remain the same.

The tendency is now toward one strong massive wing on each side—the monoplane instead of the biplane. Indeed, present production is confined almost wholly to the monoplane design. Twin motors, or even quadruple motors, in the heavier planes have largely displaced the single motor, although many of the lighter planes are still propelled by a single engine. In the main, the propeller has been set at the front instead of at the rear of the wings; but here too there are exceptions. Airplane bodies, instead of remaining clumsy, cratelike affairs, like the original designs, have become long and streamlined, with the rudder, vertical and horizontal stabilizers, and the elevators at the posterior end. The carriage is mounted either on pneumatic rubber-tired wheels or pontoons. Many of the better designs have landing gears which can be retracted to reduce air resistance when flying, while some amphibian planes have a landing gear capable of being adjusted to either land or water.

In addition to the more general aspects of improvement in airplane construction, there are certain specific advances in design and control which hold particular interest. One of these is the change in motor construction. Heretofore, in America, the motor cylinders have been arranged radially or in V-shape. We seem to be approaching the end of that type of engine. For as the diameter of the motor unit increases, more power is used up in overcoming air resistance; finally, no matter how much power is added, no increase in speed is obtainable. The tendency now, to avoid this handicap, is toward motor cylinders set in line, as in most automobile motors.

Along with better motors have come improved propellers and more efficient wing construction. Recently one of the prominent airplane-manufacturing companies has produced a light pursuit plane capable of climbing 5000 feet a minute. In 3 minutes it can reach an altitude of over 15,000 feet, and with throttle wide open can fly at a speed of more than 500 miles an hour. Since bombing planes usually fly at an altitude of from 15,000 to 25,000 feet, the makers of this interceptor plane state that it can engage an invading bomber in three or four minutes after it is sighted.

Many planes are now equipped with de-icers. When flying in cold, rainy weather, or in warmer weather at altitudes where freezing occurs, ice accumulation is a great hazard. A number of planes have been forced to a disastrous landing as a result of it. Incrustation is heaviest on the nose, leading edges of the wings, and trailing edges of the wings and the tail. On the rear edges the accumulation resembles icicles on the eaves of buildings. By equipping these parts with covers that may be alternately inflated and deflated,



Transcontinental and Western Air

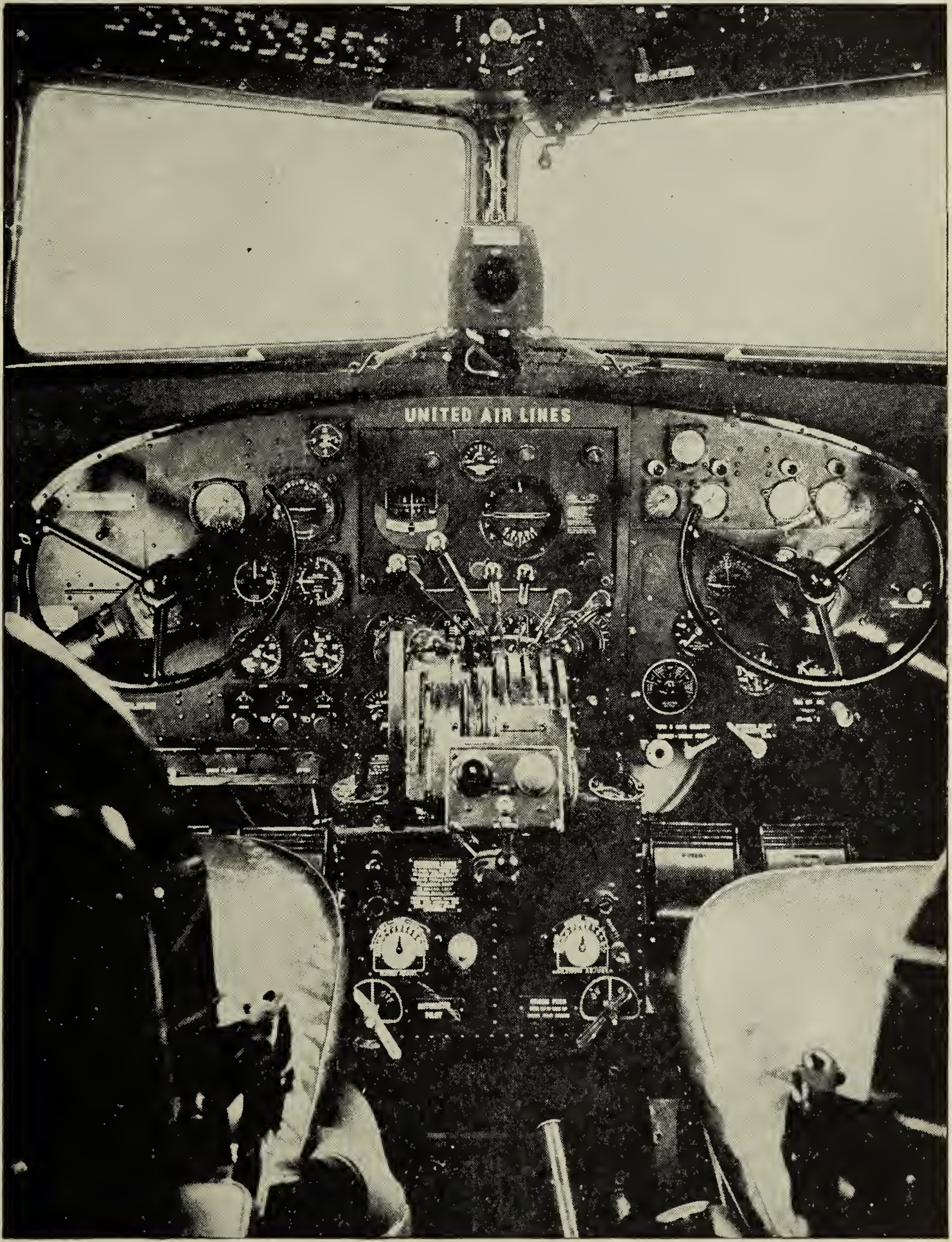
An airplane equipped with de-icers (on the edges of the wings and tail)

Below left, showing how the de-icers are attached to produce pulsations; right, the finger points to the tube through which fluid is ejected onto the propeller blades to prevent ice formation "overshoes" as they are often called, the ice may be broken into fragments which the rapidly moving air carries away as it whistles back over the outer surface of the plane. Lubricating agents are now being employed, also, to prevent ice incrustation.

Since ground communication by radio has become important in airplane operation, static electricity has been found to be a serious factor to deal with. The plane surface in flight is rubbed by the air molecules, grains of dust, and water particles as the plane speeds through them. This naturally has a tendency to accumulate an ear-choking static charge on the plane. Moreover, it interferes with the operation of other electrically or radio controlled devices on the instrument panel. It has recently been found that by attaching what is called a *static suppressor* this difficulty may be largely overcome. The suppressor in principle consists of a spring cartridge some six inches long and two inches in diameter which is mounted at the trailing edge of the wing. It contains a suitable length of fine braided wire. When static interference grows severe, the pilot or copilot sets off the cartridge, which drives the wire out in an extended position, so that by the principle of electrical diffusion the static charge is quickly dissipated from the plane. When properly installed, this device is said to remove 95 per cent of the static.

Formerly aviators were greatly handicapped in foggy weather or in stormy weather when visibility was low by being unable to tell just how far they were above an object on the earth, such as a city of skyscrapers or a mountain range. Their altimeters would indicate their elevation above sea level, but not the distance above some particular object. For this reason, in a fog, mountain peaks presented an extreme hazard. In fact, just about one half the disasters suffered by regular commercial airplane lines arose from this source.

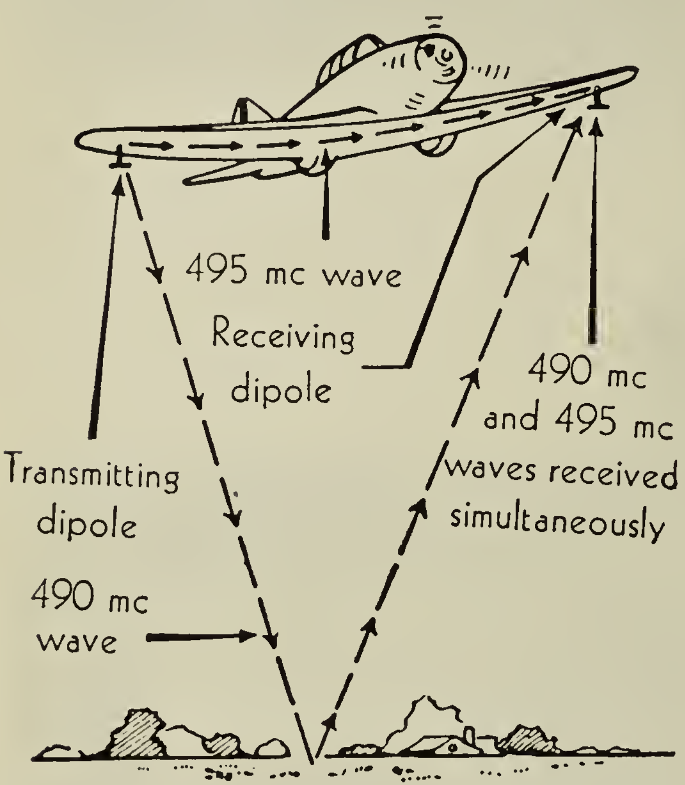
Recently, however, an absolute altimeter has been perfected. This device registers on a dial, not the sea-level altitude, but the absolute distance to the nearest sizable object over which the pilot may be passing. It works on the short-wave-echo principle. On the outer end of one wing is a dipole short-wave radio transmitter, which sends a directed beam of one wave length across toward the outer end of the other plane wing, where there is a receiving antenna. Simultaneously with the transmission of the first beam another beam of a different wave length is directed downward toward the earth. This beam traverses the distance to the earth and is echoed (reflected) back to the receiving antenna on the opposite wing. The difference in the time that the two messages, or wave lengths, take to reach the outer end of the opposite wing receiver is automatically translated into altitude distance and can be read directly from a dial indicator. This device will work effectively through



UNITED AIR LINES

United Air Lines

Instrument panel of modern transport plane distances of from 4000 to 5000 feet. It is also possible to project the echo beam at any angle through a quadrant measured by vertical distance straight down to horizontal distance straight ahead. This latter feature makes it possible for the aviator to measure distance from the plane to objects, such as a mountain range, straight ahead, as well as to objects below him. Don Fink, a writer in *Aviation*, pictures vividly just how effectively this new safeguard to flying works.



United Air Lines

A diagram illustrating how the absolute altimeter works

The reception of the wave lengths simultaneously registers on the dial in the ship the absolute altitude

> To a half dozen of us sitting in the little whitetailed Boeing transport . . . the thing seemed almost incredible. Pilot Bill Little had swung us out over the Hudson soon after the takeoff. As the plane flew along above the water, the pointer of both the TC ["Terrain Clearance," the new altimeter] indicator and the sensitive Kollsman [a superior old-type altimeter] mounted next to it, of course read equal heights. But as we crossed the George Washington Bridge [whose roadway is 250 feet above the water], believe it or not, the TC indicator flickered downward exactly two hundred and fifty feet. Then as we swung westward across the high bluff of the Palisades it dropped four hundred feet, thus showing us our exact height—not above sea level but above the ground immediately beneath us.[1]

We have found in connection with radio that directed radio beams of short length are possible. This principle has been applied to airplane-piloting. A directed, narrow, fan-shaped, short-wave radio beam is sent out from the station toward which a plane is traveling; the plane's receivers pick up this beam, which is then followed in to the desired destination. In landing, the pilots may be assisted by marker radio beacons, which indicate distance from the landing runway and position with reference to the edge of the landing field.

The gyropilot is also a most important adjunct to airplane operation. This device is too complex and technical in principle to admit of its explanation here. Suffice it to say that its primary rotating axis is set with reference to the rotational axis of the earth. In addition, it may also be oriented with reference to some point, as an airplane port. When placed in mechanical

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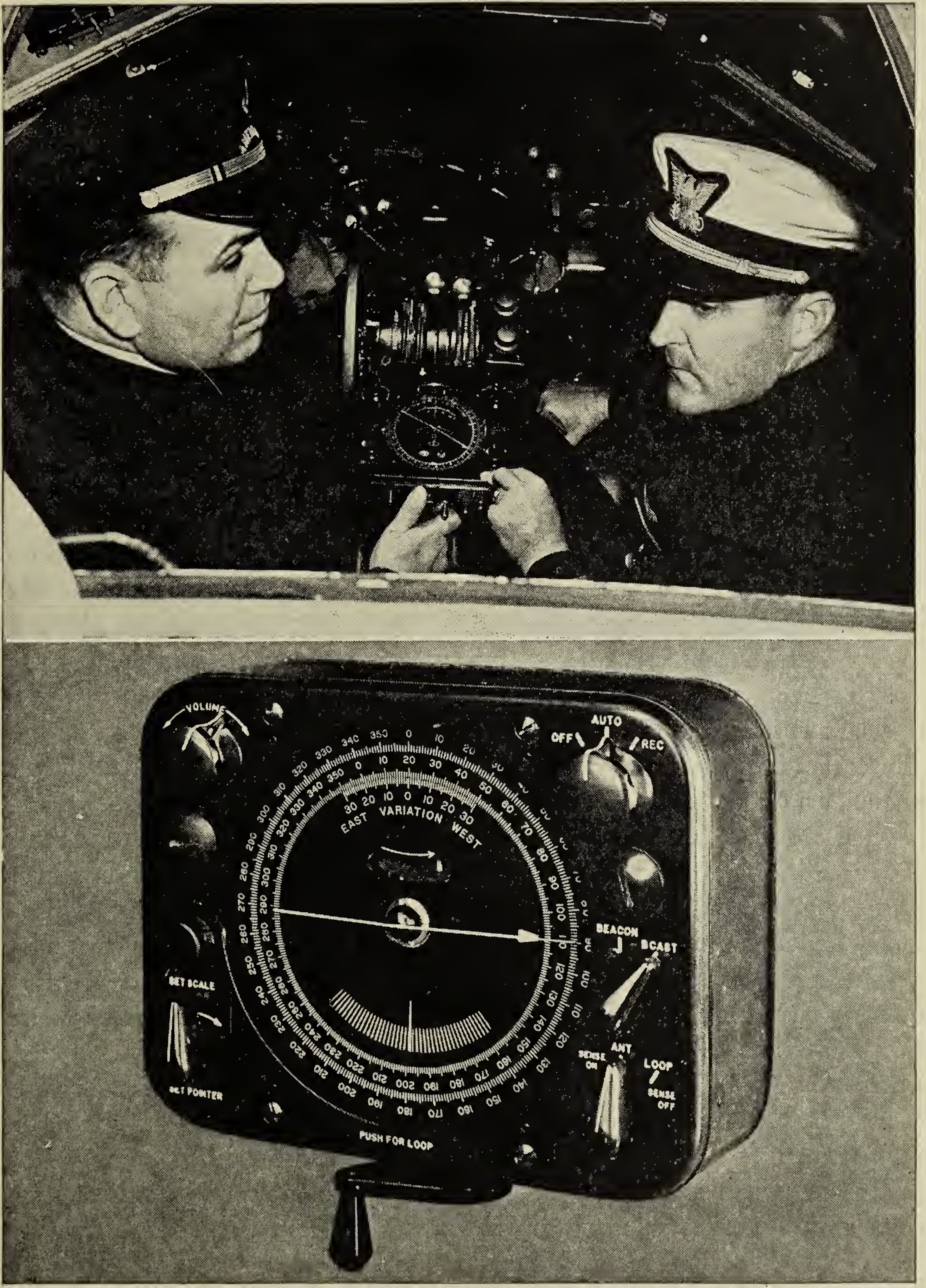
[1] *Aviation*, Vol. 37, p. 55. (1938)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Sperry Gyroscope Company

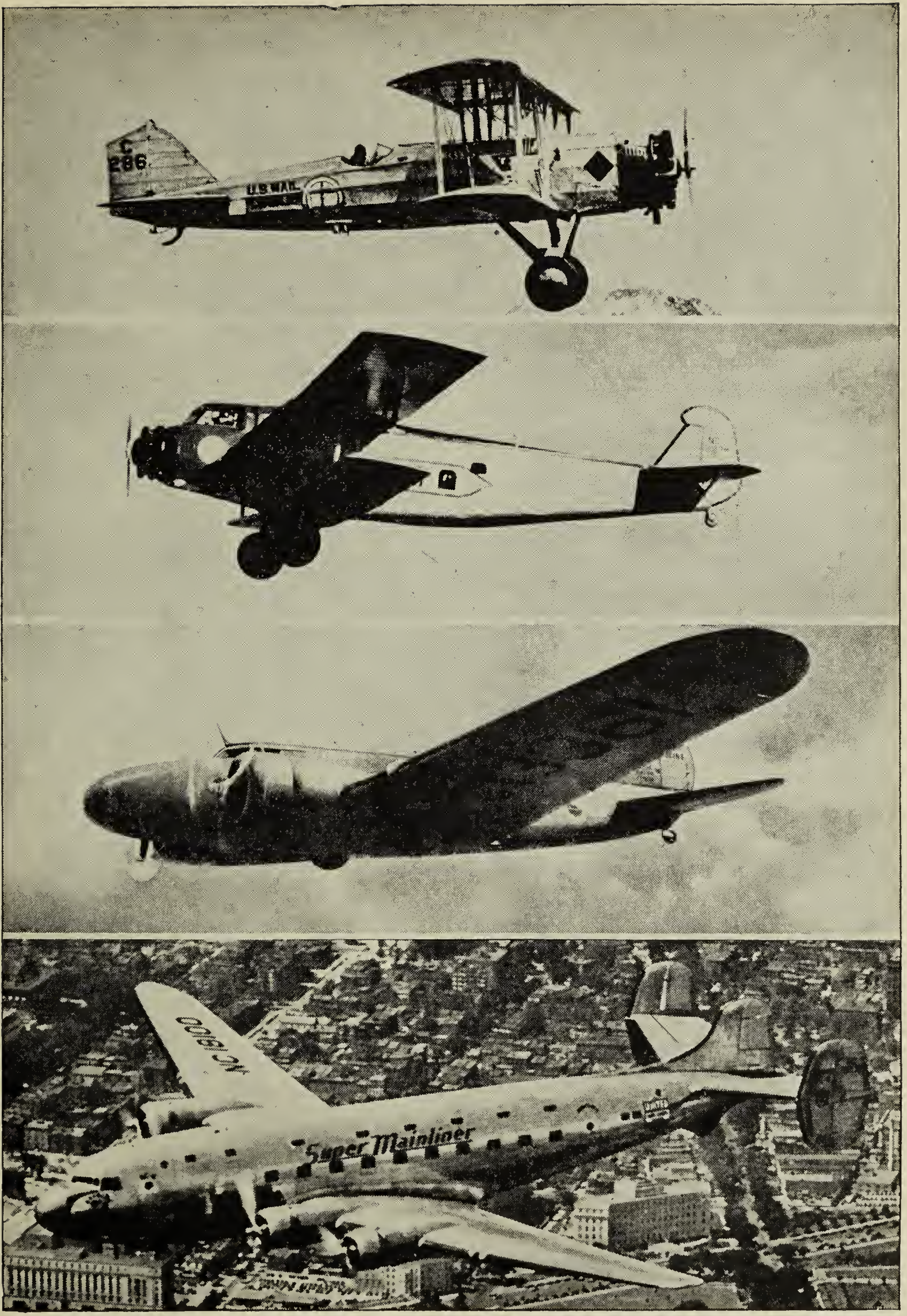
The radio compass

Above, radio compass in the cockpit of a plane; below, a close-up of the dial control of the plane, it holds it on the chosen course with surprising exactness. Ships at sea are also steered in the same way. The gyropilot has become so important in aviation that it "is today at the controls nine tenths of the time that commercial airliners are aloft." This means less fatigue for the pilot, more time for him to attend to other things in connection with the plane's operation, and, consequently, greater safety for the passengers.

Airplanes in Modern Life. In 1927, when transcontinental airplane travel was first put into effect in the United States, it took 33 hours on regular schedule to fly from New York to San Francisco. Moreover, this flight was interrupted by 14 regular stops. Today, owing to extensive improvements of various kinds, both in the plane and in the ground accommodations, surprising aerial speeds have been attained. Frank Fuller in the transcontinental air race on September 2, 1939, flew from Burbank, California, to Bendix, New Jersey, in 8 hours, 58 minutes, 8.4 seconds, or at the rate of 273.14 miles per hour. The regular schedule for passenger planes between New York and San Francisco has been cut to 16 hours, and for through planes there are but three regular stops en route. Whereas the first pilots flew small, two-passenger, single-engine, cratelike biplanes, the monoplanes of today are big, powerful machines with a surprising array of modern conveniences for the passenger.

The most powerful and elaborate commercial airplane yet produced in the United States is the DC-4. It has a wing span of slightly over 138 feet and an overall length of almost 98 feet. It requires a crew of five and carries 42 day passengers or 32 sleepers. Equipped as a sleeper, it weighs 22½ tons and is designed for a cruising speed of 200 miles per hour. This plane is a marvel of modern convenience. Complete intercrew telephone connections are provided, and at terminals, by plugging in a ground connection, passengers may talk to any telephone in the world. Baggage, instead of being stored in a rear, inaccessible compartment, is placed adjacent to each passenger, as in a Pullman car. Dictaphones are available for the businessman, and both hot and cold water are supplied to the lavatories. A private drawing room with separate dressing room is available as a de luxe accommodation, and each passenger compartment is fitted with individually controlled air-conditioning. The galley is provided with a refrigerator, hot-food compartment, electric toaster, percolator, and other culinary conveniences. And lastly, one of the baggage rooms is a refrigerated room for carrying perishable commodities.

This ship inaugurated regular transatlantic airplane service in May, 1939. The flight eastward was made in 29½ hours, and westward, allowance being made for the time difference, in 24 hours, or an average of 170 miles per hour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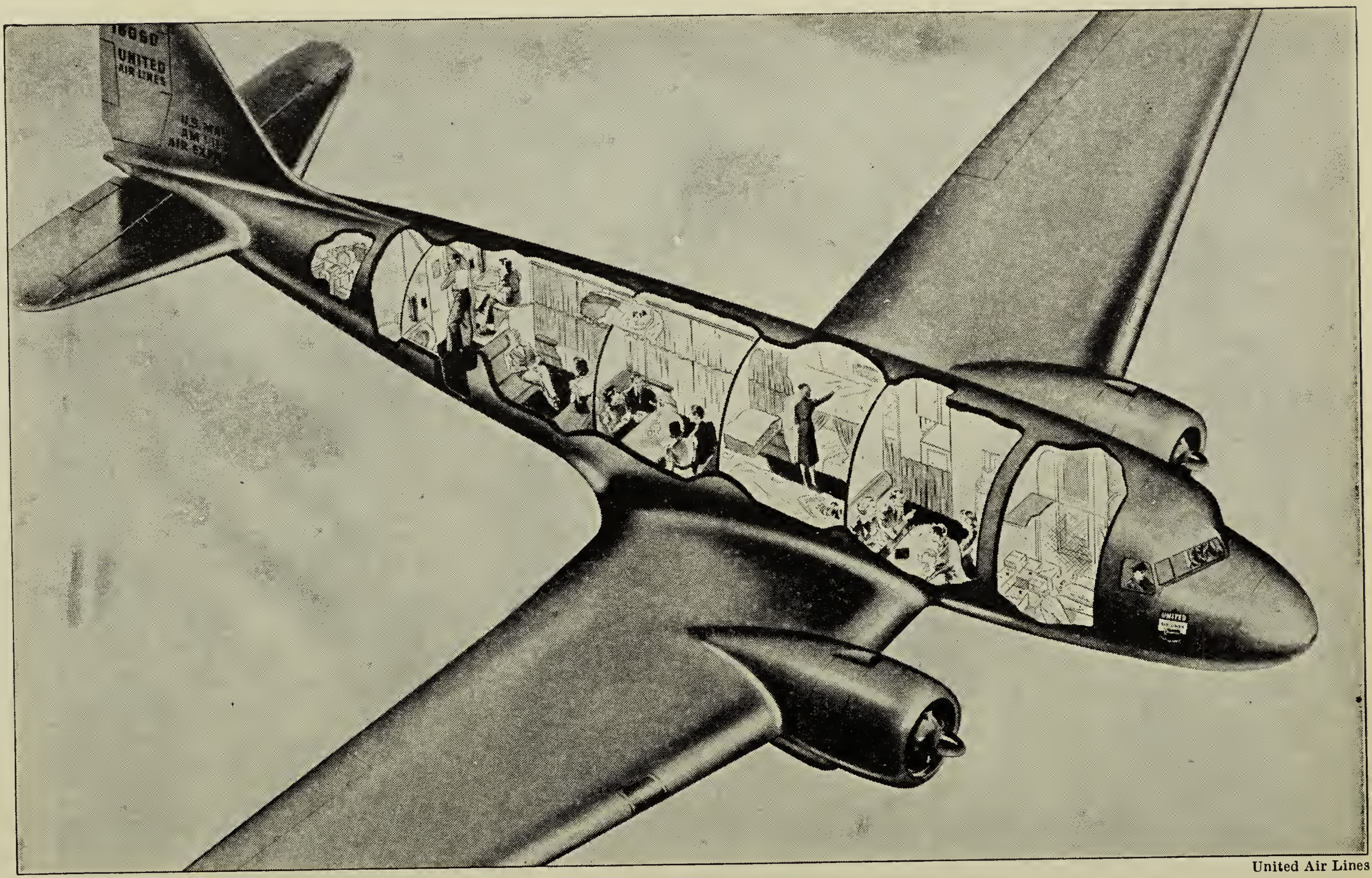
United Air Lines

Development of United Air Lines continental planes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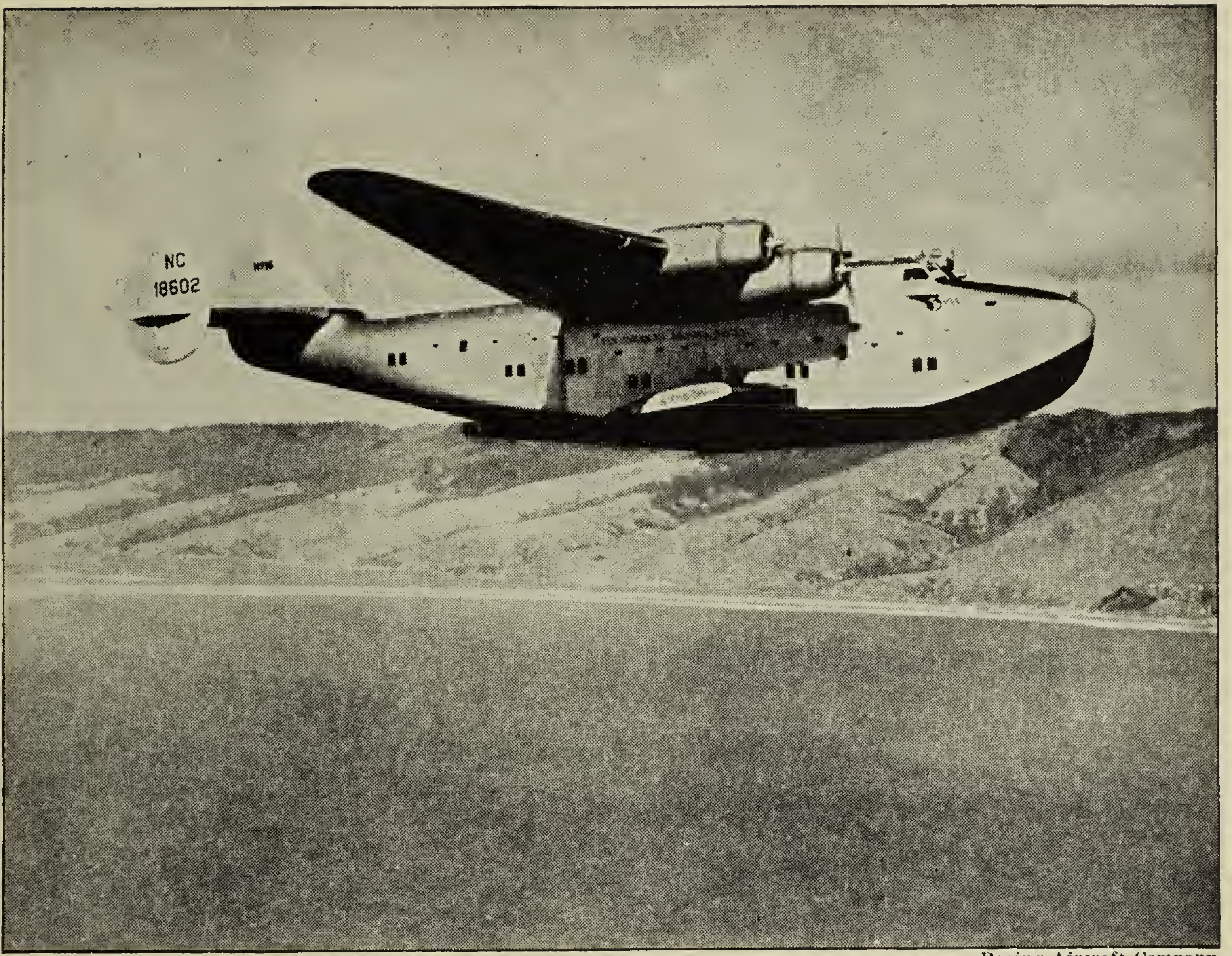
UNITED
AIR LINES
U.S. MAIL
AIR EXPRESS

United Air Lines

Inside a transcontinental sleeper



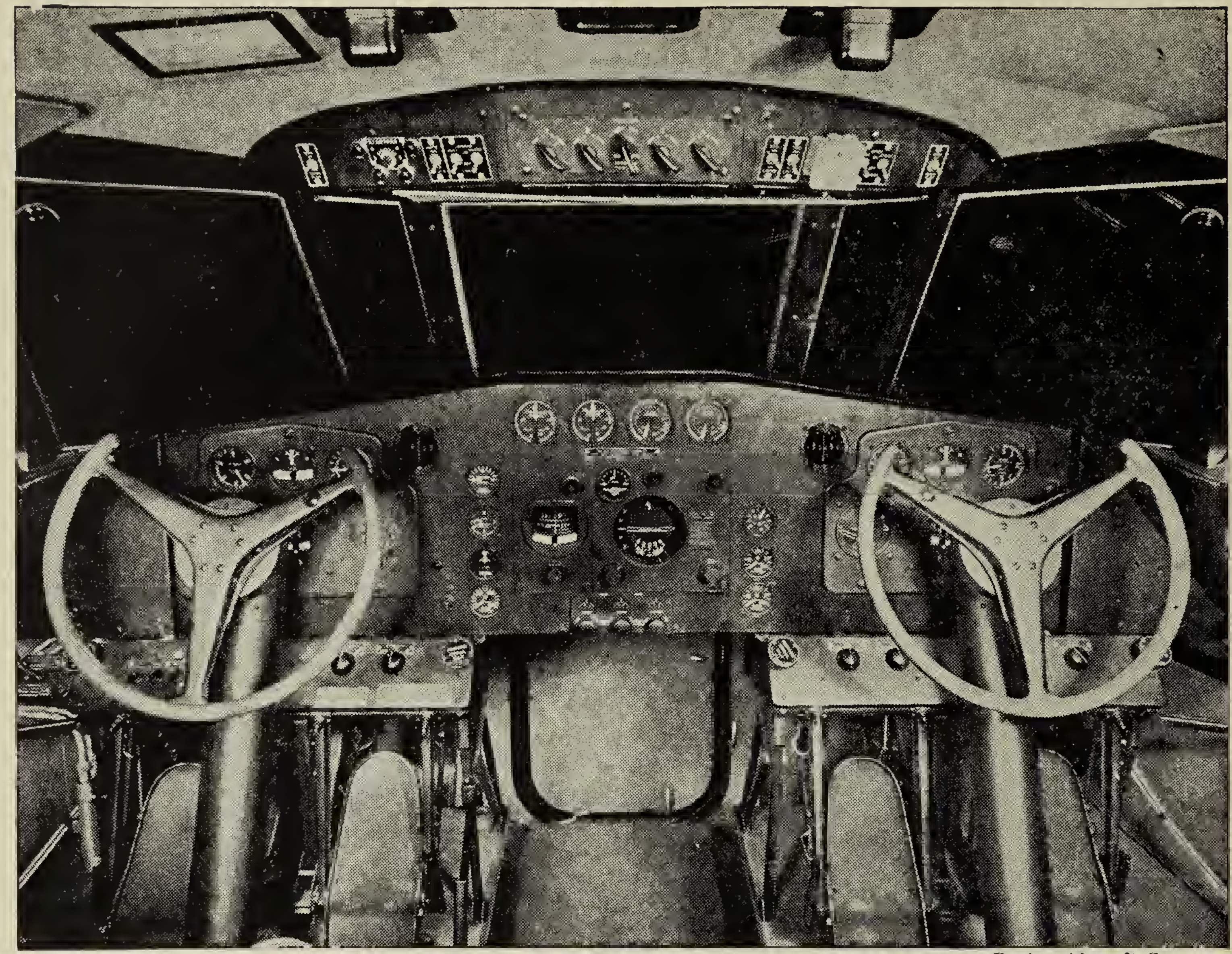
Boeing Aircraft Company

Boeing plane 314, which weighs 41¼ tons loaded

for the round trip. In April, 1942, a bomber plane was ferried from Newfoundland to Britain, a distance of 3300 miles, in just 600 minutes, an average of 330 miles per hour.

In 1941 there were 124,311,220 passenger-miles flown by scheduled airline-operators in the United States, with about 30,000,000 miles flown for each passenger fatality. Upward of 22,000,000,000 pound-miles of mail were carried, and about 10,485,058,005 pound-miles of express were flown.

A fast pick-up mail service has been inaugurated recently over fifty-nine Pennsylvania, Delaware, Ohio, and West Virginia towns. From one of the airports near New York City a mail plane flew a prescribed circuit and took on mail from the smaller cities along this route without landing. The mail pouches were picked up by a special grappling device while the plane was in flight, much as mailbags are now taken aboard speeding railroad cars by the conventional side-arm mail hook. Light express was later added to the trial service, and packages up to 35 pounds in weight were delivered, while parcels weighing as much as 20 pounds were taken on board in flight. The trial proved so successful that now scores of towns are served in this way.

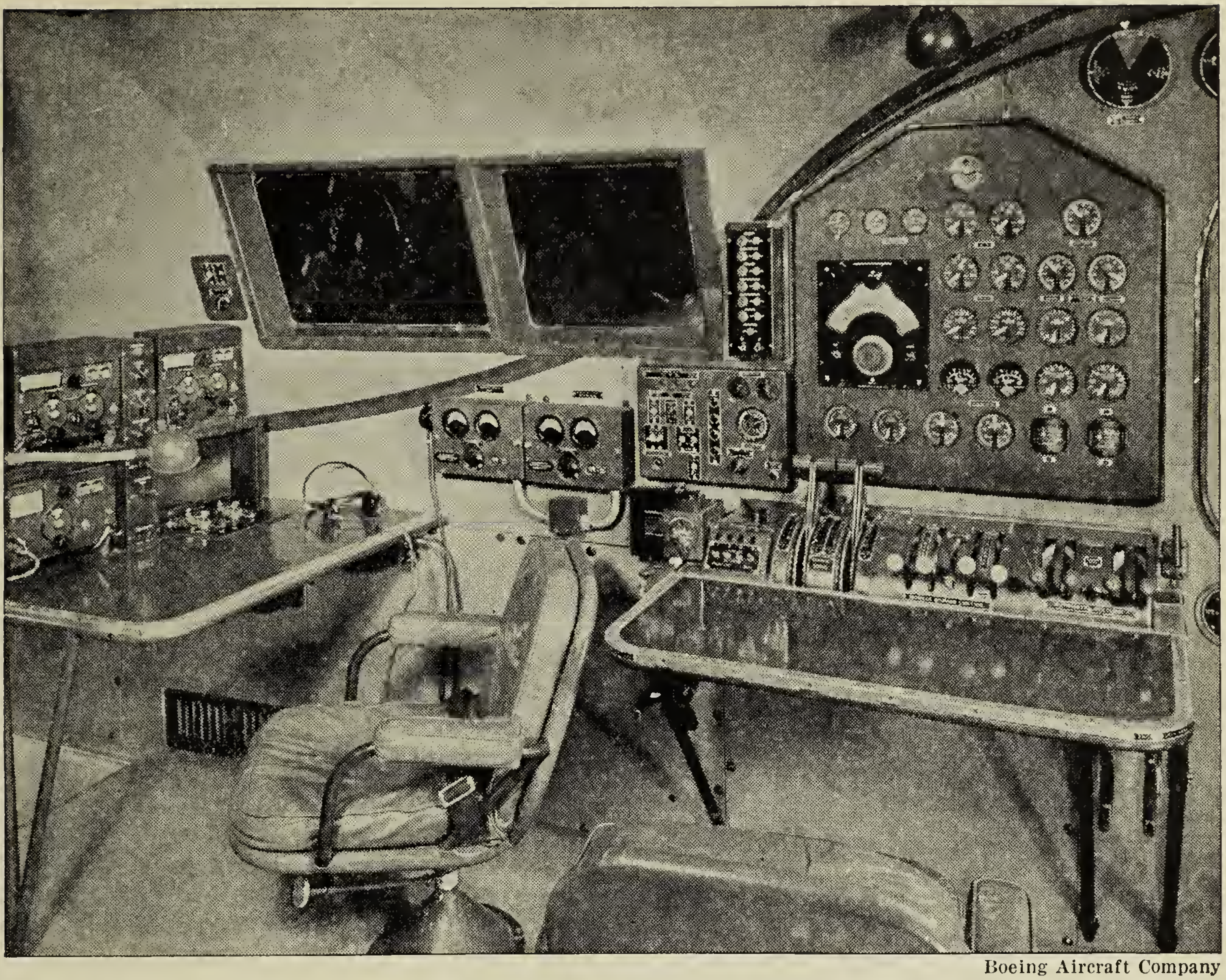


Boeing Aircraft Company

First and second pilots' stations in Boeing 314

Taken as a whole, the industry seems just in its infancy. During the second World War transportation by airplane has advanced by leaps and bounds. Huge transport planes that carry twenty-five soldiers with their light-arms equipment are in service, with planes of still larger capacity in prospect. Heavy freight transports are being used in many branches of the service, and in some instances the loaded plane itself tows a flight of glider planes, each with its cargo of soldiers, equipment, or supplies. The technological development most anticipated perhaps is a plane that can both take off and land vertically like the clumsy helicopters, and one that is so designed that the air currents flow over it evenly. Hugh L. Dryden of the National Bureau of Standards says,

> When we learn how to make air currents flow evenly across the wings of the planes ships will need but one fifth of the power now used to travel 200 to 250 miles an hour. Nations and private airplane companies are all trying to solve this problem. Perhaps it will be achieved by changing the shape of the wing. We don't know yet. But it will be done sooner or later. And when it is done the power now used could propel a transport ship 500 to 600 miles an hour.



Boeing Aircraft Company

Control room of Boeing 314

Questions for Study

1. How is the illumination produced in the different kinds of incandescent lights that are encountered in a modern city of the United States?

2. Why do you suppose that Edison probably did not foresee the present developments in incandescent lighting when he perfected his first electric light?

3. What are the basic scientific principles involved in the operation of the modern electric light?

4. What are some of the factors that should be carefully provided for when arranging the lighting for a student's desk?

5. What basic improvements in the efficiency of incandescent lights have been made within the last three or four years?

6. How have the improvements in lights and lighting contributed to the wide use of the automobile in modern life?

7. How can an airplane fly when it is many times heavier than air?

8. What are some of the most important advances that have been made in airplanes since the first successful flight of the Wright brothers?

9. How does the airplane compare with the automobile in regard to (1) speed, (2) control, (3) and safety?

10. What are some of the safety measures now used on all leading airlines to ensure safe, comfortable transportation?

11. What airplane routes can you find on a map of the world designed to show these lines of transportation?

12. How are the various steps in scientific thinking exemplified in the development and improvement of the airplane?

13. Wherein must a pursuit plane differ from a bomber?

14. What effect is the modern airplane having upon international relations?

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CHAPTER TWENTY-FOUR

Sound Is Propagated by Waves

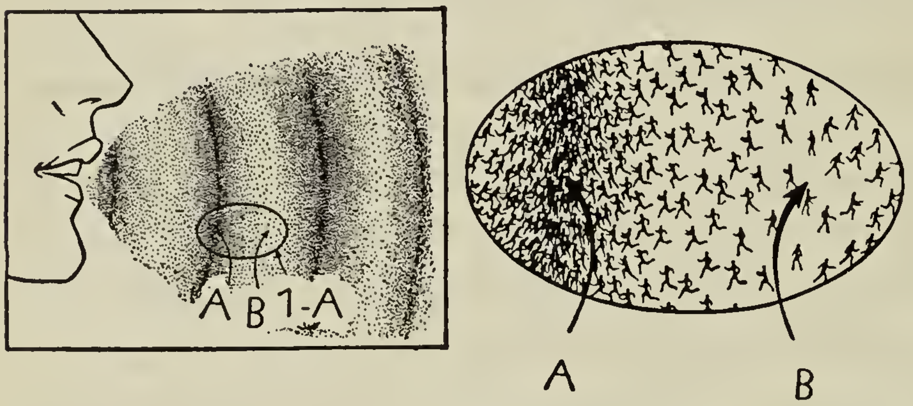
Sound Is Produced by Waves. Sound may be thought of as a form of energy, and its source is always some vibrating body. Anything which moves in air disturbs the air. A vibrating body pushes the elastic air in front of it, and, since the molecules of air cannot instantly get out of its way, a layer of compressed air is formed at that point. Likewise, since the molecules of air behind cannot instantly crowd into the space just vacated by the air in front of them, a layer of rarefied air is formed in this space. This disturbance, then, consisting of a compressed region of air followed by a rarefied layer, travels outward in all directions, and we have the physical basis of sound. Continuous sound, it is obvious, consists of a series of these alternate compressions and rarefactions following one another in succession like waves on the surface of the ocean, the chief difference being that sound waves travel out in all directions from the emitting body, whereas ocean waves affect only the molecules of water on and near the surface.

It now becomes evident that sound waves are different from light waves. A sound wave is chiefly an air wave, and under ordinary conditions is propagated only where there are air molecules to form and carry it. If an alarm clock were suspended in a completely evacuated bell jar, it might ring all day without disturbing the slumber of one whom it was intended to wake, even though it were placed close by his bed. Light waves, on the other hand, which are radiant-energy waves, require no air either to form them or to convey them. They are electromagnetic waves and seem not to need any material medium for their propagation.

That sound waves possess energy is shown in many ways. A loud, near-by report, as of a gun, is painful to one's ears. Indeed, artillerymen often plug their ears with cotton to deaden the shock to their eardrums. A heavy explosion may break windowpanes for miles around. The air compressions sent out from the explosion tend to bend the glass in. Consequently it is quickly pushed out again by the recoil from the compressed air on the inside when the rarefied portion of the wave strikes the pane.

Sound waves take an appreciable time to travel from their source to the hearer. In this respect they are much less speedy than light waves, which, the reader will remember, travel about 186,000 miles a second. Steam can be seen to issue from a distant train whistle long before the sound can be heard.

The thunder that accompanies lightning may not be heard for several seconds after the flash is seen. We were told as children that if one could count five in the interval between the flash of lightning and the thunder, then the lightning was a mile away. Like many other popular ideas, that statement is approximately correct; we count five in five seconds, and sound travels about 1000 feet each second. Careful experiments were carried on in Europe in 1822 and 1823 by Moll and Van Beek to determine the velocity of sound. Cannon were fired at different distances, and the time for the sound to travel back to the listeners was carefully noted. The average velocity of sound was found to be about 1090 feet per second at 0° C. Subsequent study with electrical recorders has reduced this value very slightly, but for nontechnical purposes this figure is often used.



American Telephone and Telegraph Company

Diagrams illustrating how sound waves travel

Right, graphic enlargement of 1-A

Other substances besides air will convey sound waves. A compression can be made to travel in a plank of wood, a rod of steel, or a tank of water. Indeed, any medium that possesses elasticity can be made to convey sound. These denser materials are much more difficult to compress, however, than air, and for this reason the force which they exert as they spring back to their original condition is greater. Steel is 1,200,000 times less compressible than air, and it is 6030 times more dense. Sound travels almost 3 miles per second through steel, or 14 times faster than in air. If one with an acute sense of hearing applied his ear to a water pipe and let someone at a suitable distance strike it a sharp blow with a hammer, the listener might be able to hear three sounds. One would come through the metal pipe, one through the water in the pipe, and the other through the air, and in this order. Many of us have laid a watch at one end of a long table and heard it tick distinctly by applying our ear to the opposite end of the table. Sound waves can travel through ten feet of wood better than through one foot of air.

Sound Waves May Be Reflected. When sound strikes an object, the waves may be reflected. We are all familiar with the fact that in certain locations, when a person speaks loudly or shouts, the sound of his voice will come back to him. Hard, smooth surfaces have the property of reflecting sound waves, or producing an echo. As with light, here too the angle of reflection is equal to the angle of incidence. In mountainous regions secondary echoes may occur, owing to the reflection of the voice from one surface to another surface and then back to the ear. In being so reflected, the sound loses intensity with each reflection, and consequently the secondary echoes are progressively fainter. A series of echoes arising from a single source is called a reverberation. Thunder is particularly characterized by its long, rolling, or sharp, staccato-like reverberations. These prolonged echoes come from adjacent clouds, mountains, hills, and other objects.

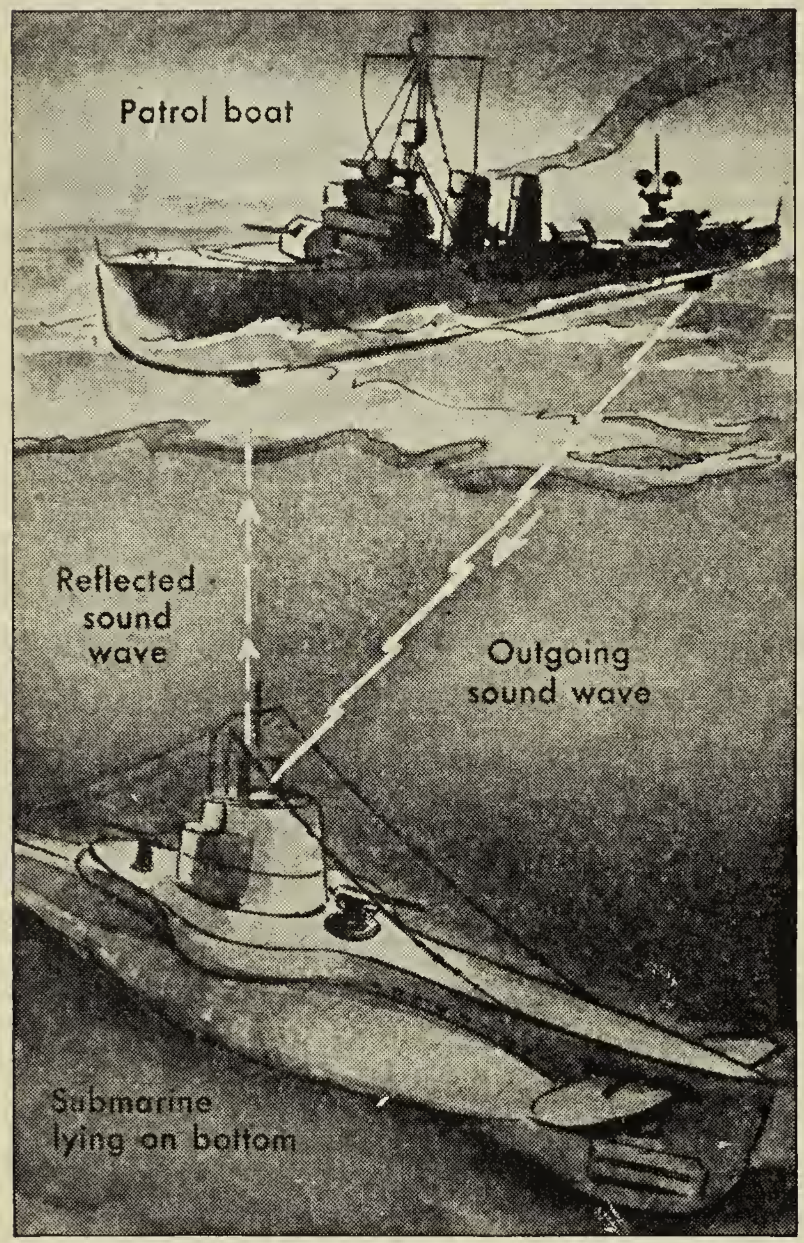
When the voice reverberates, owing to the varying distances of the sound-reflecting surfaces and to secondary echoes, one syllable of a word may overlap an earlier reflected one. If this occurs, indistinct hearing results. Auditoriums with such defects are said to have bad acoustics (Greek *akoustikos*, "relating to hearing"). It is said that one may sit in the great cathedral of St. Paul's in London, not fifty feet from the lectern from which the scriptural lesson is being read, and be unable to follow the most familiar passage because of the bad acoustics of the structure. Every sound wave is echoed and re-echoed up and down that vast space, so that the result is a confused welter of sound waves.

With the introduction of sound pictures, especially, it has become necessary to prevent the persistence of sound waves in the theaters. This is done by covering the walls with loose hangings or by building the room with acoustical material. In this way the energy possessed by the sound waves is absorbed and deadened after it has fulfilled its mission of conveying energy from the loud-speakers to the ears of the hearers.

Very large buildings are often constructed with high arched ceilings, like that of the Capitol dome in Washington. It is possible to hear even a low tone at a distant point in such an auditorium, since the sound is reflected from the ceiling and concentrated at the point occupied by the listeners. The famous Mormon tabernacle at Salt Lake City is so arranged that practically all sound from the speaker's stand is directed toward the audience. It is said, though this may be an exaggeration, that a pin dropped at this particular point may be heard in remote parts of the building.

Echoes Are Used in Sounding. Formerly there was only one way to determine sea depth. That was by the use of a sounding device consisting chiefly of a weighted steel wire which was gradually played out from the drum on which it was wound. This was a slow laborious process and could be followed accurately only when the sounding vessel was at rest. But vessels which are moving often need to know the depth of the ocean at frequent intervals. Particularly is this true in a storm or when approaching a strange coast.

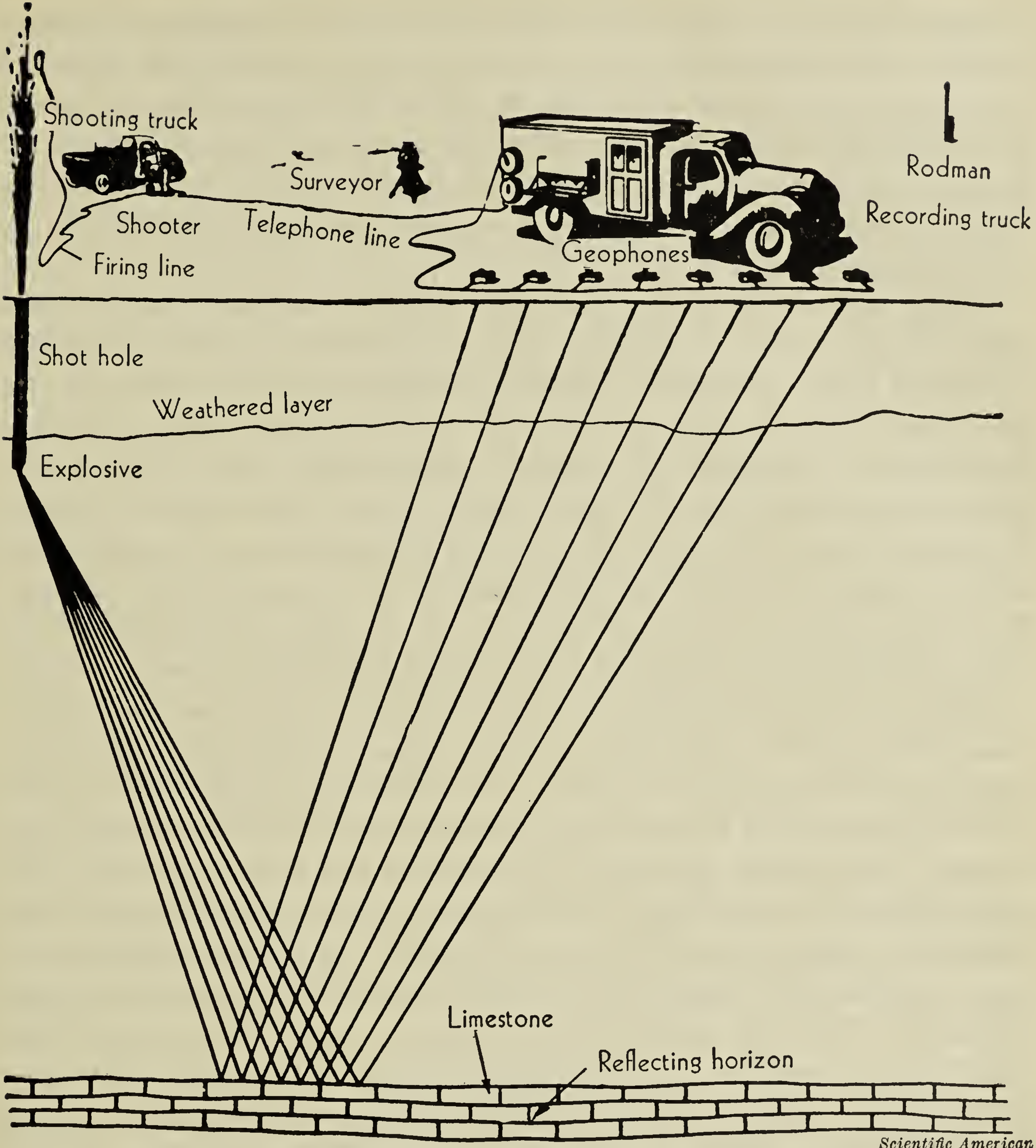
The principle of echo sounding has made such information easily possible. A sound of desirable intensity is transmitted downward from the ship. The exact time of transmission is electrically recorded. When the sound wave strikes the bottom, it is reflected back again to the vessel. Here it is automatically received and the exact time of reception electrically recorded. Since the velocity of sound in sea water is known, it requires but a simple, rapid calculation to determine the depth of the water through which the vessel is moving. Indeed, it may be read approximately from prepared charts. By this method dependable soundings may be taken every few feet of the vessel's progress.



Scientific American

Echo sounding may be used to locate objects under water

The principle of sound-wave, or vibration, transmission has also come to be used to locate mineral deposits. By this method artificial earth tremors are produced near the earth's surface by firing charges of dynamite in holes drilled to a depth of from 40 to 100 feet. The firing of the charge creates a sound wave, which spreads out in all directions. Portable seismographs (instruments to record the exact time and intensity of earth vibrations) are placed at a number of temporary stations within a radius of 10 or 20 miles. Each time an outgoing wave encounters a different reflecting stratum, a small amount of energy is reflected back toward the surface. Thus dense metallic deposits and compact rocks form a better reflecting surface than pools of oil or looser formations, such as sand and clay. The reflected vibrations are picked up by seismometers or geophones, amplified by vacuum tubes, and recorded on a strip of paper. A study of these records, including the time it takes for the sound wave to reach the various strata and be reflected back, makes it possible for geologists to form a chart which indicates something of the character of the subsurface strata. By using


Shooting truck
Surveyor
Rodman
Recording truck
Shooter
Telephone line
Firing line
Geophones
Shot hole
Weathered layer
Explosive
Limestone
Reflecting horizon

Scientific American

Echo sounding is used to locate mineral deposits underneath the surface of the earth

comparative seismographic records from different stations and applying careful computations, the location and the extent of any particular area or layer may be determined by its sound-reflecting properties. This method, it is obvious, will not reveal directly the presence of any particular deposit, such as iron, salt, gold, or oil. But the character of the waves received indicates an area of different reflecting properties from those of the surrounding geological formation; and when such records are used in conjunction with the results of other investigational methods, they have often been found to render very valuable assistance.

Seismographs are employed in warfare to determine the enemy's artillery positions. By locating these instruments at different places with respect to the direction from which the enemy's explosive fire seems to be coming and by considering the time and direction of the earth waves created by these explosions, and to some extent the relative intensity of the waves, considerable evidence may be gained as to the points upon which defensive artillery fire should be concentrated.

During the first World War, submarine raids by the enemy were, at the outset, hard to combat because the submarines could not be located. A method of locating them was finally worked out which depended on the principle given above. If a vessel saw a submarine and was within sounding distance of the shore, it immediately exploded a charge under water. Several submerged microphones near the shore picked up the sound waves traveling through the water. A brief calculation showed the position of the submarine, and fast destroyers or bombing planes could be sent in pursuit. In the second World War elaborate sound-amplifying devices are being used constantly from many listening posts to detect the approach of either submarines or aircraft.

Differences in the sound-transmitting properties of various bodies have many other practical applications. Before a fast passenger train leaves the station, the wheel-inspector goes along the whole length of the train, tapping the car wheels with a hammer to see whether dangerous cracks have begun to form. Automobile mechanics, trackwalkers, and others who work with metals utilize the sound they hear when they tap a piece of metal to find whether the parts are safe for the use intended. An engineer can often tell more accurately by sound than by sight whether his engine is operating efficiently. Those who handle coins drop them on a hard surface to hear their "ring" if they suspect a counterfeit piece. The physician uses the stethoscope (Greek *stethos*, "breast" + *skopein*, "to view") to listen to his patient's heart or lungs when diagnosing thoracic troubles. Or, with his fingers, he taps the abdomen or other parts of the body and learns much concerning internal conditions from the resulting sounds. Healthy organs and flesh when tapped do not emit the same sounds as do gas-inflated or pus-filled areas.

Musical Sounds Are Produced by Regular Vibrations and Are Characterized by Volume, Pitch, and Quality. A sound that has a regular period of vibration, like that of a ringing bell or a vibrating violin string, is a musical sound. When there is no regular or sustained vibration, as in the slamming of a door or the roar of a moving train, the sound is called a noise.

Every musical sound has three characteristics by which it may be identified: volume, pitch, and quality. By volume one means the loudness of the sound. A tuning fork struck lightly does not vibrate through so great an amplitude as one that is struck violently. Since a tuning fork that is vibrating sets up corresponding vibrations in the air, it is evident that the larger the amplitude of vibration of the fork, the larger the amplitude of the wave produced by the vibrating particles of the air. The more energy the vibrating particles possess, to put it another way, the greater the amplitude and the louder the sound. However, the size of the amplitude does not alter the musical sound in any other way. Its pitch and quality remain the same.

The frequency in vibration determines whether a musical tone is a high or a low note. If a card is drawn slowly along the teeth of a comb, a low pitch is produced; but if it is drawn more rapidly, a higher-pitched tone results. Every time the card slips off one tooth and strikes the next, a sound wave is started in the air. The more waves produced in a given time, and hence the shorter the waves, the higher the pitch. The range of pitch for the human voice is from about sixty vibrations per second for low bass to about sixteen hundred for a high soprano.

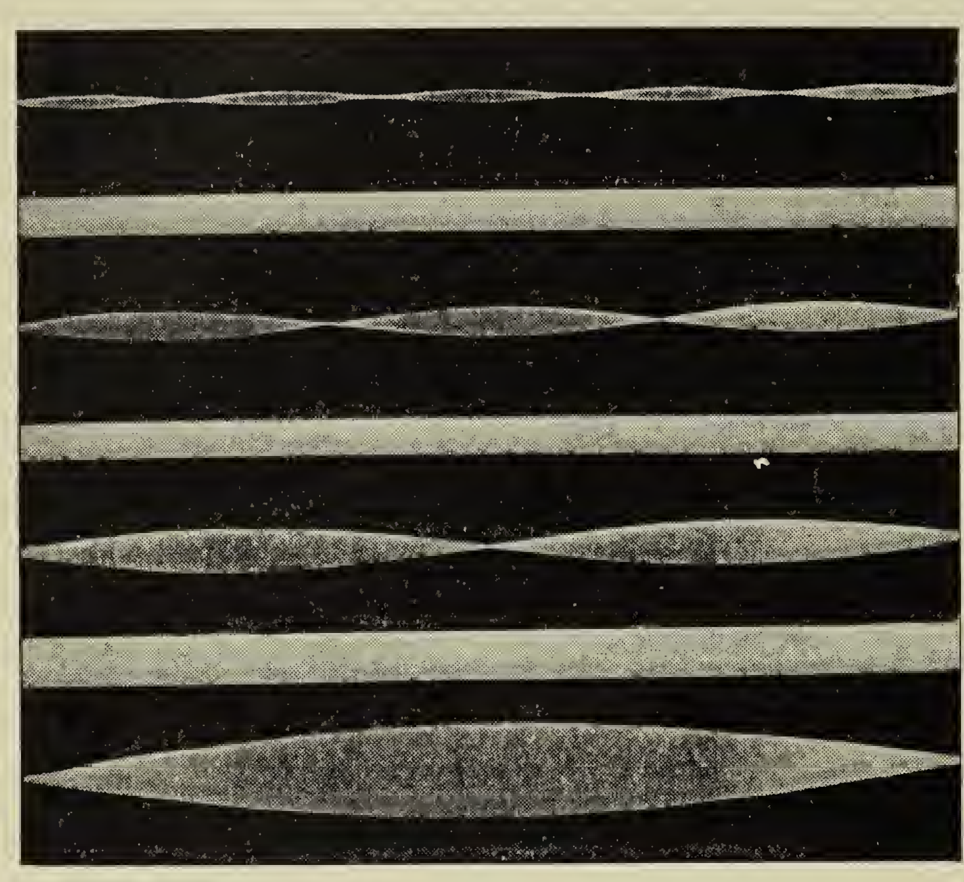
Musical sounds of different pitches are arranged in a series of scales called octaves. This form of expressing the physical relationship of tones was standardized under Pope Gregory I in the sixth century A.D. Each scale consists of eight notes, which are designated by the first seven letters of the alphabet. If we begin at middle C, the notes forming the next higher octave are C, D, E, F, G, A, B, C. The next lower scale is similar, except that here the pitches of the tones in the scale as one goes down from middle C are successively lower.

It is obvious, then, that sound waves vary widely as to length. The following table gives some notion of the relation of pitch, frequency, and wave length:

Wave Lengths in Air

Source and Pitch of Musical Sound	Frequency	Wave Length in Air at 20° C
Lowest organ note	16	70.7 ft
Lowest piano note	27	40.3 ft.
Low C of bass voice	65	17.4 ft
Middle C	256	4.4 ft
High C of soprano voice	1024	1.1 ft
Highest piano note	3500	.324 ft

The human ear cannot detect sounds that are very low-pitched or that are very high-pitched. About this there is some difference of opinion among physicists. This difference of opinion probably arises from the fact that individuals differ in their ability to detect differences of pitch. Some persons can distinguish lower tones than others, and some higher tones. Kaye tells us that the average ear can perceive a range of frequencies from about 20 to 20,000 vibrations per second, but that ordinarily attention is largely restricted to ranges from 50 to about 5000 vibrations for speech and from 35 to 7000 for music. So there must certainly be many sounds emitted in nature to which the human ear is deaf.



A string vibrating as a whole, below, and in segments, above[1]

We discussed the Doppler effect in connection with the analysis of light waves. This effect is even more evident in connection with sound waves. The pitch of a locomotive whistle rises as the train approaches and falls after the train has passed. As the train approaches, the waves are shortened; hence a greater number of vibrations per second reach the ear than when the train is stationary. After it rushes past, the waves are lengthened, owing to the movement of the emitting whistle away from the auditor. Consequently the pitch of the tone seems lower. The noise from airplanes passing low overhead produces the same auditory effect.

Most sources of musical sound produce several tones simultaneously; that is, the whole sound heard is a mixture of pure tones. When a string of a violin, for example, is made to vibrate, it vibrates not only as a whole but also in segments. Each segment is capable of producing a tone, as well as the whole string. Since the number of vibrations per second depends in part upon the length of the string, the pitch of any vibrating portion is always higher than that of the whole string, or fundamental. The multiple vibrations produced by the segments are called overtones. The quality of a tone, then, depends on the number and the relative intensity of the overtones present. Some musical instruments are capable of producing more overtones than others, and we say that their tone qualities are better. The human voice has unusual possibilities in this respect.

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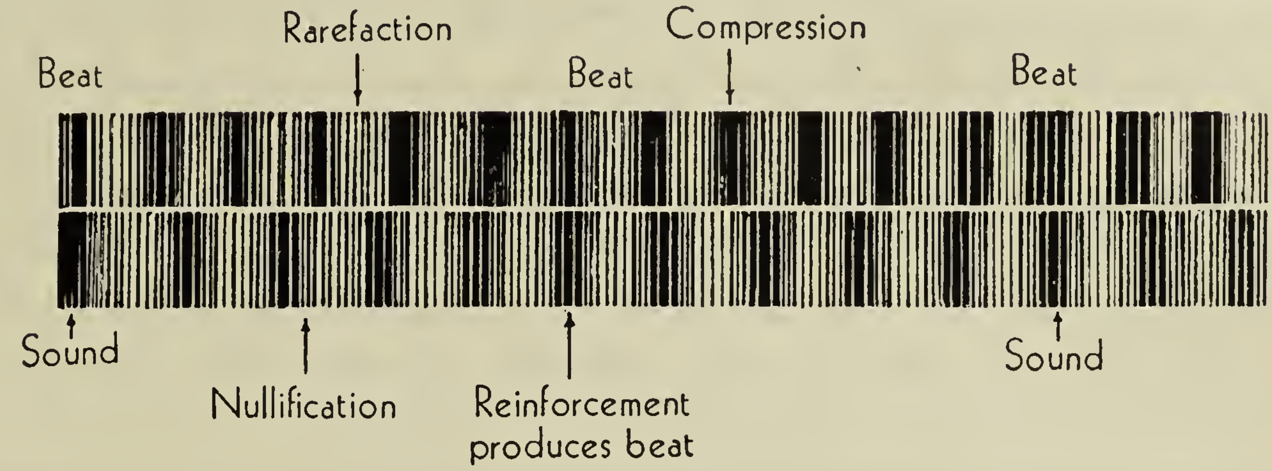
[1] From *The Science of Musical Sounds*, by Dayton C. Miller. By permission of The Macmillan Company, publishers.



A diagram to show reinforcement and nullification of sound waves, producing beats

The compressions of air are represented by the dark bands and the rarefactions by the light bands

People are becoming more exacting in their demands for tone quality in radios and phonographs. They are no longer satisfied with the reproduction of part of the tones only, which results in poor quality. Instead they want the rich overtones as well. High-fidelity (true-tone-reproduction) broadcasting stations too are now in demand. Their transmitters are designed to send out a wide range of sound frequencies.

Beats Are Produced by Two Close Frequencies Sounded Together. When two vibrating bodies differ but little in frequency, there are times when the air compression produced by one coincides with the compression produced by the other. At this point one wave reinforces the other, and the tone is louder. On the other hand, since the two are slightly out of step, the difference in the wave crests grows greater until finally the compression produced by one of the bodies coincides exactly with the rarefaction of the other. In this case, if the sound waves emitted by the two vibrating bodies are of equal amplitude, one will nullify the other and no sound will result. A piano tuner tightens or loosens a wire till it no longer gives beats with the note of a tuning fork. It is then in tune. To make the matter clearer, suppose two notes are sounded of equal intensity one of which vibrates 60 times per second and the other 59 times. It is evident that once every second the compression waves will exactly reinforce each other and a beat will occur. Likewise once every second the waves will fall in exactly opposite phases, and the canceling effect will result in silence. If the tension is changed so as to cause each wire to vibrate 60 times a second, the beat will be eliminated and the two will be in tune.

Resonance Is an Important Factor in Musical Tones. Owing to the energy effect of air waves, sympathetic vibrations are set up by one vibrating body in other vibrating bodies having the same period. To illustrate this, let two tuning forks of equal period be set up a couple of feet from each other. Now, if one fork be struck sharply, it will emit a loud sound. This is due to the energy of its vibration. If one listens carefully, the second fork will soon begin to vibrate gently and emit a soft tone. The intensity of this vibration will gradually increase, and in time the volume of the tone emitted will approach that of the first fork. If one sings a single note successively for some time, or if a violin string be played continuously in a room containing a piano, soft tones of corresponding pitch will presently be found to be coming from the piano wires. These tones are due to sympathetic vibrations.

Closely related to sympathetic vibrations is the principle of resonance. Almost every musical instrument consists of a vibrating part and a resonator to increase or modify its tone. In a violin the string vibrates, and the body of the violin acts as the sounding board, or resonator. In a clarinet the reed produces the tone, and the "horn" is the resonator.

A very good resonator is a glass tube that can be filled with water to any desired height through an opening in the bottom which is connected with a tank. If a tuning fork be struck and held over the upper end of the tube while the length of the air column is slowly changed by admitting water, the principle of resonance will presently be demonstrated. Soon the air column too will begin to vibrate and emit a note of corresponding pitch. In fact, if the wave length of the fork is short compared with the total possible length of the air column, there may be found not only one but several places where the air column within the tube is just the right length to reinforce the sound of the fork. When these points have been determined, the length of the tube may be carefully adjusted to one of them. Now it can be demonstrated that, although the tuning fork may vibrate so feebly that no sound can be heard from it even a few feet away, nevertheless, when it is placed over the air column, the tone produced, largely by the latter, is so amplified that it may be heard distinctly throughout a large auditorium.

The envied ability to produce a fine musical instrument is largely a matter of being able to get the desired resonance effect. This depends on the sound-producing properties of the materials used, the care with which the parts are fashioned, and the size, shape, and spatial relations of the parts. In highly perfected instruments the prized tones are due to fundamentals richly modified and enhanced by many overtones from the resonator and all so amplified as to give the desired volume. It is largely factors such as these that make the difference between the famous Stradivarius violins, worth thousands of dollars, and a cheap "fiddle" that may be purchased at a bargain-counter price.

The human voice has great variations in this respect. The pitch of the fundamental tones is determined by the length, tension, and weight of the vocal cords; but columns of air in the pharynx, mouth, and nasal cavities, acting as vibrating resonators, determine the character of the voice, whether it is harsh and displeasing or sweet and harmonious. We can distinguish our friends by the *sound* of their voices quite as well as by their facial appearances. The secret of being a good singer, aside from a sense of pitch and personality traits that may affect mood, effort, ideals, and perseverance, is fundamentally a matter of having a good pair of lungs, smooth elastic vocal cords, and head cavities capable of being highly effective as a resonator. After that, vocal training is largely a matter of developing the technical skill that will enable the singer to make the most of his native endowments. It is considerations such as these that make a Lily Pons or a Lawrence Tibbett.

Sound May Be Advantageous or Disadvantageous to Mankind. Recently sound waves have been found to have unsuspected germicidal effects. Waves having this effect are of high frequency and are called supersonic waves. For instance, an intensely vibrating nickel tube when placed in milk was found to kill approximately 80 per cent of the bacteria which were contained in the liquid. The more resistant bacterial spores, however, were not affected. Red blood corpuscles, when subjected to the effects of supersonic waves, have been found to be strained and warped, and their color has faded.

In experimental work sound waves have been found effective in smoke precipitation. Bituminous coal was first discovered in England by the action of the ocean waves which laid the coal strata bare. For this reason it was called sea coal. In 1661 John Evelyn wrote of the "hellish cloud of sea-borne coal which maketh the City of London resemble the suburbs of Hades." Since that day the smoke nuisance, despite certain measures that have been taken to secure better combustion, has grown worse. The actual cost of smoke each year to people in the United States through the wastage of fuel, cleaning buildings, and dry-cleaning clothing and house furnishings is estimated to be $2,500,000,000.

The United States Bureau of Mines has attacked the smoke nuisance with sound waves. When shrill, high-pitch sound waves are directed into a large glass tube filled with tobacco smoke, dust, smelter fumes, or the like, there is a brief turbulent motion in the dispersed matter. Then the solid particles in the gas form flakes, like soot, and fall to the bottom of the tube. Dr. R. S. Dean, Chief Engineer of the Metallurgical Division, foresees the day when it will be commercially possible to attach the device to every important chimney in a city, including even chimneys of private homes.

Sound in the form of discordant, distracting noises has been found to lower human efficiency. Consequently noise in crowded urban centers, with automobiles and motor trucks roaring by and filling the air with the sound of their horns, the clatter of industrial activity in the commercial districts, and the din and noise incident to manufacturing plants, has become a serious problem. In Rome the sounding of automobile horns is prohibited, and it is restricted in London.

In the United States the unit of measure of noise is the *decibel.* The decibel is a mathematical concept, and we shall not attempt an exact definition. However, by this scale the *average* noise of a very quiet residence is estimated at about 22 decibels, the noisiest residence 45, the information booth in a large railway station 55, a factory location 68, a subway station, while express trains are passing, 95, and a boiler factory 97.

An article adapted from "Noise Control as a By-Product of Air-Conditioning" tells us this:

> The lives of many million persons throughout the country, especially of those in urban areas, are made less enjoyable, and frequently less healthful and profitable, by the insidiously harmful effects of noise. For such as these, life becomes indeed full of "sound and fury." . . . [The effect] takes the form of neuroses, loss of sleep, excessive fatigue, emotional disturbances, increased blood pressure, decreased working and mental efficiencies, and that grave danger, noise deafness, a condition that is frequently a by-product of industrial employments. It is not unusual to find in groups of such workers below thirty years of age as many as 50 per cent with some degree of impaired hearing.[1]

According to the same authority, in a workroom in a German factory where experienced workers assembled temperature regulators, 60 imperfections were found in a group of 80 instruments. The workroom was next to a boiler shop. When this work was transferred to a quiet place, the workers assembled 110 units in the same time previously required for 80 units, and only 7 imperfections were found.

In the offices of one life-insurance company the efficiency of piecework performed by the employees was studied before and after the offices were quieted. The noise level was lowered 14.5 per cent, and the average efficiency of the workers was raised 8.8 per cent. Typographical errors were reduced 29 per cent, while the errors of machine operators were cut 52 per cent. Employee turnover decreased 47 per cent, and absences dropped 37.5 per cent.

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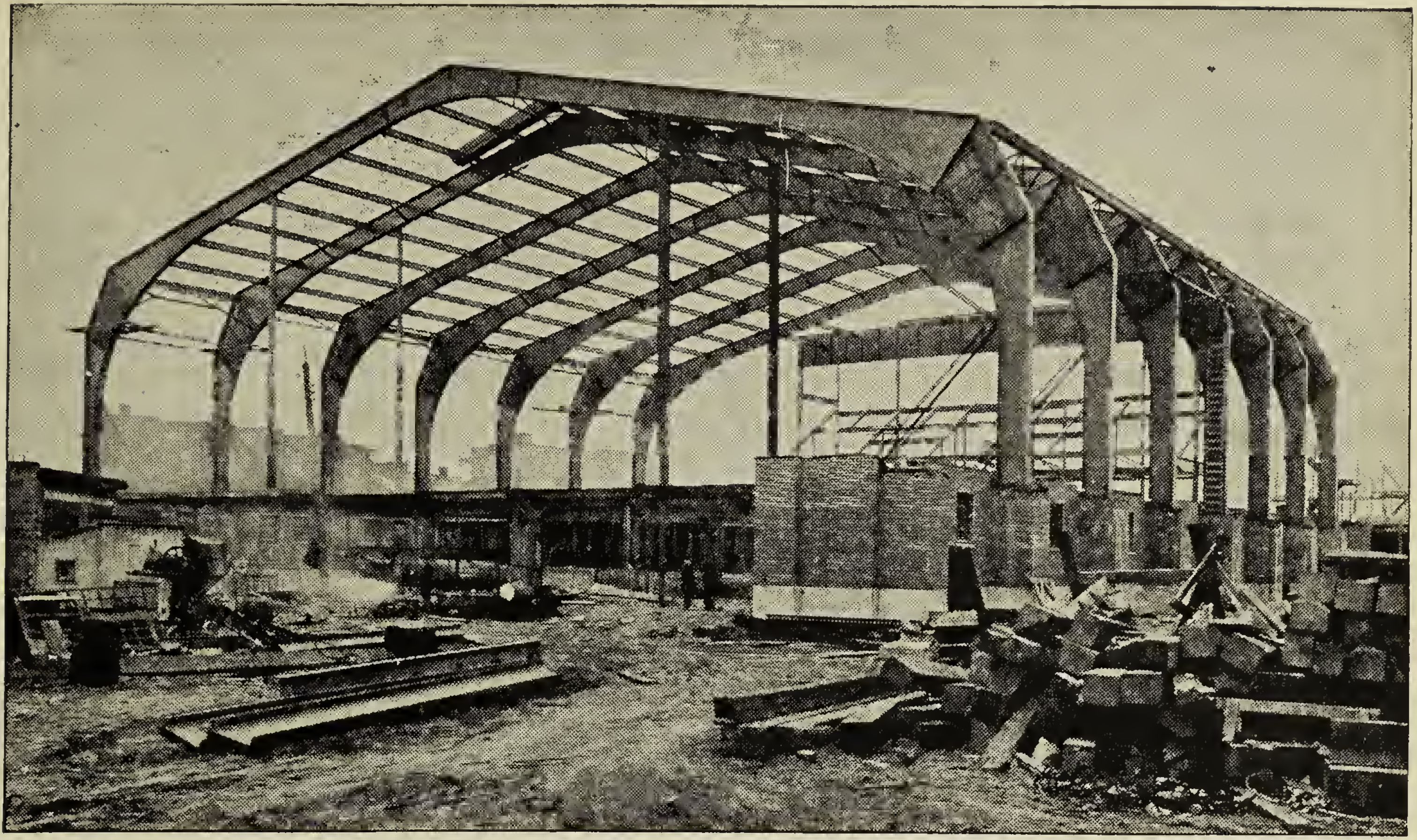
[1] Leola J. Harris, "What Kind of a Noise Annoys?" *Hygeia*, Vol. 16, p. 1085. (1938)



General Electric Company

Arc-welding

This steel structure is being quietly "sewed" together by arc-welding, free from the noise of the riveting hammer

Campaigns against the noise nuisance have already been initiated. New York has its Noise Abatement Commission. The mayor has appealed to the populace for co-operation and has charged the police with the responsibility of cutting down the noise and confusion resulting from the needless sounding of automobile horns. Industrial plants in some quarters are introducing soundproofing in plant construction and seeking machines whose operation is less noisy and distracting. Silent electrical welding instead of the earsplitting staccato noise of the rivet hammer is being employed in joining the steel beams for large buildings. Offices are being equipped with noiseless typewriters, and in some cities a municipal ordinance requires that automobiles with a double-horn installment be supplied with a switch that will cut out one horn.

Deaths from accidents reach appalling figures in the United States. For instance, in the first eight months of the second World War casualties in the United States armed forces were 4801 dead, 3218 wounded, and 36,124 missing—a total of 44,143. During the same period the casualty list of American workers was 30,000 dead and 2,500,000 wounded—a total of 2,530,000. Since noise is very disturbing to some nervous systems, it would seem from the data just given that noise abatement must become one of the prominent features of any effective safety campaign.

Questions for Study

1. What evidence can you give that sound is a series of waves in some material medium?

2. How is the normal human body equipped to produce and to receive sound?

3. How could you prove that sound travels at different rates of speed in different mediums?

4. It has been said that if the right pitch, or frequency, could be found, it would be possible to destroy a city by sound alone. How might such a statement be explained?

5. What conditions may be operative when one finds himself in a seat in an auditorium in which it is difficult to hear what the speaker says?

6. What is the difference between music and noise?

7. What properties of musical sounds distinguish them from other sounds?

8. What characteristics of sound make it possible for the trained ear to distinguish the tones of different musical instruments which are being played in a large orchestra?

9. What is meant when it is said that a radio broadcasting apparatus or other sound-projection system is of the "high-fidelity" type?

10. How is it possible for you to recognize the voice of a friend when heard over the telephone or radio or in ordinary speech?

11. What are the distinguishing differences between a pure note and one emitted by a mellow-toned musical instrument or a well-trained voice?

12. Why is it possible to hear sounds, which originate at a distance, better on some days than on others?

13. What are some of the common noises which may impair the health of those who are subjected to them?

14. How can the average citizen help to abate the noise nuisance in his city?

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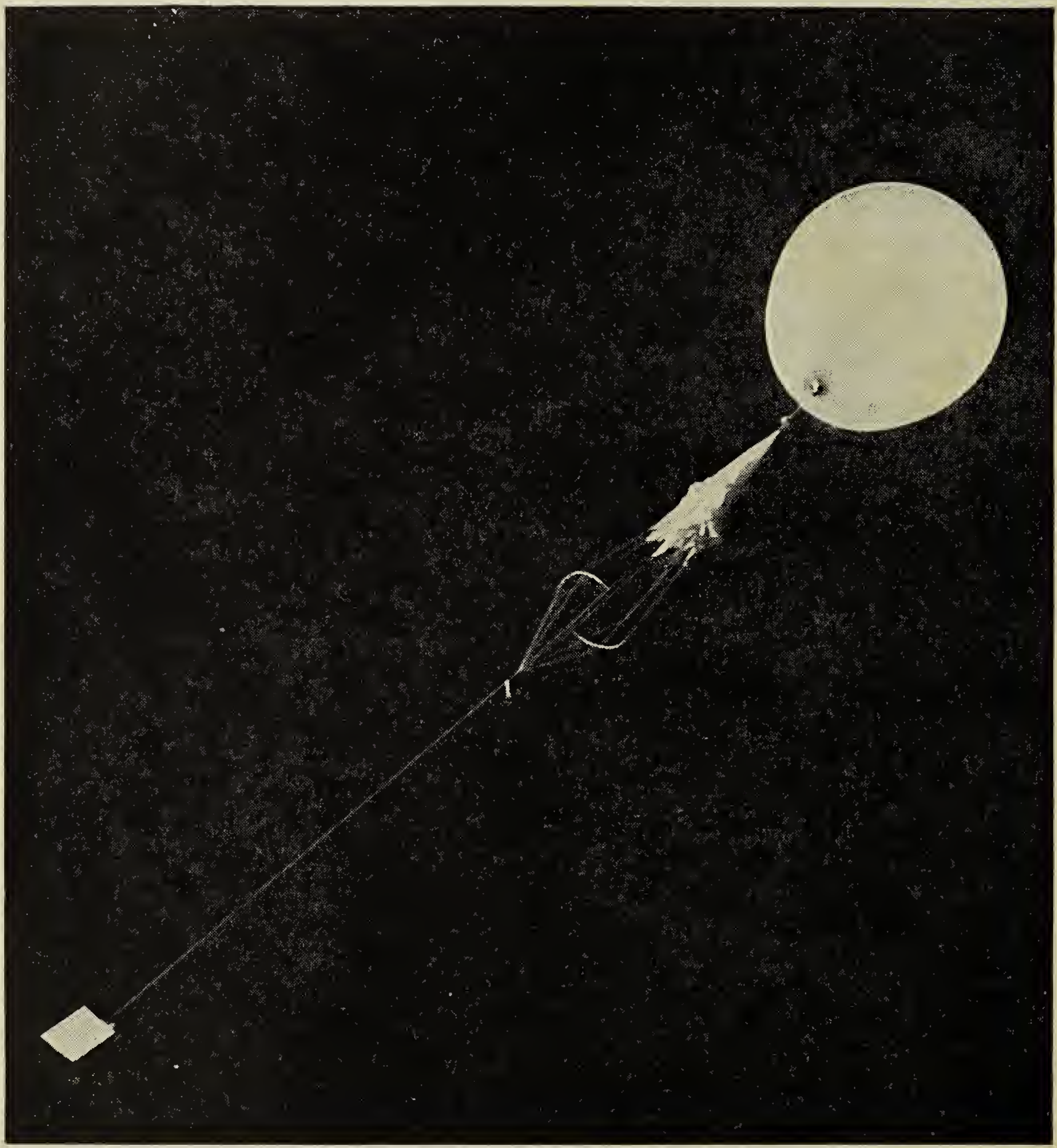
UNIT FIVE

The Hydrosphere and the Atmosphere Are the Chief Factors of Weather

The mass of the earth is sufficient to have caused it to collect about itself both a sphere of water and one of air. Not only do these fluids make life on the earth possible, but they interact on a grand scale and in a complicated manner with the radiant energy that comes from the sun. The interrelations of these forces and conditions make sunshine and rain, tropical and frigid zones, calm breezes, and raging storms. They are the basis of climate and weather. They determine whether different areas of the earth are to be covered with verdure or are to lie as barren, monotonous wastes. They determine largely how people in different regions are to live, and whether they must spend most of their time struggling for a mere existence or whether they shall have time for intellectual pursuits. Indeed, these factors are so potent that they often not only set the limits of human habitation, but determine the character of the industrial, economic, and social life which the people must adopt to survive.



Radford, from United States Department of Agriculture

Pilot balloon with radiosonde

CHAPTER TWENTY-FIVE

The Earth Possesses Characteristics Which Make Life Possible

An Atmosphere Is Necessary to Support Life. Whether a celestial body is inhabited by living forms depends in part, at least, upon whether physical conditions there are of such a nature as to support life. One of the important conditions is an atmosphere. A serious question raised in connection with the problem of life on Mars is that of atmosphere. That there is a certain gaseous envelope about that planet is not questioned; but whether it is sufficiently dense and whether it is composed of the elements necessary to support life as we know it is another matter. Some, as a result of study and investigation, think it is; others, on equally good grounds, doubt it.

In this respect, from man's point of view, the earth is most fortunate. We have just found that it is a relatively dense planet, and this property greatly increases its mass. Because of its gravitational pull, it has been possible for it to retain an extensive atmosphere that plays a many-sided part not only in climatic and weather conditions but also in human affairs. It furnishes oxygen for breathing and combustion; it transmits sound; it is concerned in the supply of rain and snow to the earth; it reduces the intensity of the sunlight; it greatly modifies temperature conditions; and, finally, it furnishes some of the necessary food components to plants, from which man gets energy, body-building materials, clothing, and fuel.

The Earth's Atmosphere Is Believed to Have Developed Gradually. There is a question as to whether the earth at the outset had an atmosphere. If the earth grew from a nuclear center by planetesimal accretion, as Chamberlin believed, it would have had to attain about one tenth its present size for gravitation to become sufficient to hold gaseous molecules about it. Assuming that it was built up in this way, the atmospheric gases would come from two sources: in the first place, it is probable that a large quantity of gaseous matter existed among the larger planetesimals, and, in the second place, enormous quantities of gaseous materials must have been expelled from the accumulating solid material under the influence of heat and variable pressure. Chamberlin has shown that meteorites when heated in a vacuum may liberate several times their own volume of gas. It has also been found that metals when heated under the same condition will yield small volumes of different gases.

The Earth's Atmosphere Is Very Extensive. No one knows accurately the extent of the earth's atmosphere, but by gradual accretion it has come to be very great. It forms a gaseous shell certainly a hundred miles deep, and its depth probably reaches two hundred miles or more. Owing to gravity and the compression of the superimposed layers, however, by far its greater mass lies relatively close to the surface. It is estimated that fully half the air lies within the first three and a half miles.

Because gases, like other fluids, transmit pressure equally in all directions, we are accustomed to think that the air is very light. We can move through it with apparent ease except when it happens to be driven by a stiff gale. Compared with solids its density is small, but in its entire volume its weight is enormous. If one exhausts the air from an airtight container and weighs the container, then readmits the air and weighs it again, the second weight will be found to be appreciably greater than the first. Then, if the air pump be reversed in direction, and air be forced into the container, its weight will be found to increase directly in proportion to the degree of compression.

The great weight of free air at the earth's surface is due, of course, to its great volume. Just as when books are piled up in a stack, we find the weight resting on the bottom book to be greater than that resting upon any other book in the pile, so it is with the air. The deeper down we go into this great mantle of atmosphere, the greater the pressure due to the weight of the air above. At sea level the weight of a column of air 1 square inch in cross section and as high as the atmosphere extends is 14.7 pounds. This does not seem to be a great amount, and yet it is greater than the steam pressure maintained in the radiators that heat our homes and public buildings. This compression results in the air's actually weighing at sea level $1\frac{1}{4}$ ounces per cubic foot. The mass of the air may be more fully appreciated when it is found that the total pressure exerted on an acre surface at sea level by the weight of the air above it is 46,100 tons. The pressure falls rapidly with altitude. At eighteen thousand feet the pressure is about half as much as at sea level, and at thirty-six thousand feet it is about one fourth of the original amount.

The Atmosphere Is Composed of Many Gases. At sea level the air is composed chiefly of two gases, nitrogen and oxygen. The former comprises about 78 per cent of the atmosphere by volume at this level, and the latter approximately 21 per cent. The oxygen is the active agent, as we have found, which supports oxidation, including decay. The nitrogen, on the other hand, is an extremely inactive gas.

As a component of the air nitrogen dilutes the oxygen and helps to maintain conditions on the earth as they are. If there were more oxygen, things would not be as they are, for fires would be too destructive. If there were much less oxygen, we could hardly have fire at all.

The nitrogen in the atmosphere also furnishes a vast storehouse of this element which man can, by chemical processes, combine with other elements to produce substances invaluable to society. Other important components of the air are water vapor, which, at sea level, on an average, makes up about 1.2 per cent of the atmosphere, and carbon dioxide, which amounts to but approximately 0.03 per cent. Although the comparative amounts of these two gases appear at first glance to be almost negligible, yet the gases are of tremendous importance. Without their presence, even in these dilute proportions, conditions upon the surface of the earth would be completely changed.

The minute amount of water in a small volume of air is unimpressive; but when the total amount of water in the vast atmosphere surrounding the whole earth is taken into consideration, it becomes of the greatest importance. It is from this diffuse reservoir of gaseous moisture that clouds are formed and that all precipitation in the form of rain, snow, hail, and dew comes. Without it the earth would quickly become a dry, barren, and parched waste. There is no time when it is not raining somewhere on the earth. It has been estimated that the average amount of rain and snow falling over the entire earth's surface reaches the surprising figure of sixteen million tons per second. Water vapor also determines the humidity of the atmosphere and is important in affecting the temperature conditions. The amount of water in the air decreases very rapidly with altitude. For instance, at a height of something like three miles it drops to about one fifth of 1 per cent, and above this level it becomes almost negligible.

The carbon dioxide content of the air, although extremely low, is of equal importance with that of water vapor. As will be seen later, it furnishes the carbon component for all forms of both plant and animal food. The carbohydrate foods are not only highly important as energy producers but also form the foundation upon which the protein-tissue-producing foods are built up.

Carbon dioxide, derived chiefly from mineral decomposition, volcanic eruption, decay of organic matter, combustion, and plant and animal respiration, is a relatively dense gas. For this reason, when not disturbed by winds and strong convection currents, it tends to remain in the lower levels of the atmosphere. As a result, it often gathers in old wells, mine shafts, and silos. In the case of silos it is liberated by the fermentation taking place in the enclosed silage. By becoming concentrated in such places it gradually dilutes the oxygen and produces a condition known as "damps." If a person descends into a damp-infested mine, for example, he very quickly suffocates. If a lantern or burning paper be sent down, it is extinguished the moment it enters the region in which there is insufficient oxygen to support combustion. Many persons have lost their lives by descending into these abandoned structures without first testing them with a flame.

In addition to these four highly important gases, the atmosphere contains small amounts of other gases. These are not of great importance as constituents of the atmosphere, but some of them have come to possess considerable commercial value. Among these are helium, argon, and neon.

Dust in the form of suspended particles is also an important component of the atmosphere. It consists chiefly of minute particles of inorganic material of all kinds and is usually invisible except when it occurs in clouds. Smoke, volcanic ash, and bits of salt left in the air as a residue from evaporating ocean spray are important in this connection. Organic particles too, such as very small seeds, spores, and bacteria, have been found to be a rather abundant constituent. Dust particles are naturally more abundant in the lower atmosphere, but some of them are carried to a height of several miles. Special traps placed on the wings of airplanes show that the spores of fungi are not infrequent at heights of two miles or more.

Many of these particles approach molecular dimensions and are not visible with the aid even of a powerful microscope, but they are important in connection with atmospheric condensation. They serve as nuclei about which water particles collect as they form mist, fog, and rain. They also, either alone or when surrounded with a film of water, intercept some of the radiant energy coming from the sun. Following a violent volcanic eruption the average temperature of practically the whole globe has been found to be reduced. In mid-ocean from 500 to 2000 minute dust particles per cubic centimeter have been found, and in the dusty cities the count has run up to more than 100,000 per cubic centimeter.

Up to the floor of the stratosphere (see p. 461) the relative proportions of the various atmospheric gases, with the exception of water vapor, do not change. This condition is due to air currents which keep the gaseous components of the air well mixed.

The Air Is Greatly Affected by a Change in Temperature. In relation to living forms upon the earth the temperature-regulating influence of the atmosphere is highly important. In a certain sense it may be said to act as a heat trap, much as a greenhouse does. If one enters a greenhouse on a clear spring day, even though there is no heat in the pipes, he is struck at once by the difference between the outside and inside temperatures. It may be from 10° to 15° warmer inside. This difference arises from the fact that the greenhouse catches the sun's rays, which readily penetrate the glass. These radiations, both visible and invisible, collide with, or impinge upon, the benches, flowerpots, walks, and even the green leaves of the plants themselves, and much of their energy is transformed from radiant energy into heat. Solar radiation is predominantly of *short* wave length; thermal radiation from inside is of relatively *long* wave length, and is prevented from escaping by the glass walls and roof of the greenhouse.

The atmosphere of the earth acts much like the glass in the greenhouse. The air, except when filled with particles of dust, vapor particles, and clouds, offers comparatively slight resistance to the radiations as they come down through it from the sun; but when these rays are transformed into heat, which raises the temperature of the earth's surface enormously, and then into long-wave-length terrestrial radiation, they find themselves trapped in much the same way as the rays in the greenhouse. The heat that would escape as longer radiation waves is absorbed by carbon dioxide and water vapor. Consequently the atmosphere keeps the earth continuously bathed with thermal radiation. Were it not for this gaseous envelope, the earth, like the moon, would almost reach a boiling temperature during the day and then, at least on land surfaces, drop to a temperature far below zero every night.

The mean temperature of the air at the earth's surface is approximately 52° F. This decreases on an average about 17° F for every mile of elevation until, in the North Temperate Zone, a height of approximately seven miles is reached. At this point the temperature has fallen to approximately – 65° F. It was formerly believed that this temperature continued about constant up to the approximate outer limits of the atmosphere. This conception is now known to be erroneous. The stratosphere at present is regarded as extending up about 30 miles in the North Temperate Zone, which would bring its top to from 35 to 40 miles above sea level. It is known to vary in respect to elevation as one goes from the equator to the poles. In equatorial regions it begins at an elevation of about 11 miles, but in polar regions its lower limit drops to a height of from 4 to 5 miles. Because of this wide difference, at different latitudes, in the distance from the earth at which the stratosphere begins, the temperature of the stratosphere base also varies greatly. The temperature falls, as we have found, at the rate of about 17° F for each mile of elevation. For this reason the temperature of the lower stratospheric boundary over the equator is in the neighborhood of – 112° F. In the region of the poles, however, a different condition prevails. There, although the stratosphere overhangs an area of very low land temperatures, its altitude is so low that it is not much colder than the surface air. The figure usually given is about − 40° F.

The height at which the stratosphere begins over a particular locality may fluctuate considerably, depending upon conditions. Observations made at St. Louis, Missouri, have shown that the temperature at the base of the stratosphere may vary from − 36° F to − 78° F. This would indicate an altitude range of from 4.7 miles to 7.5 miles.

A Knowledge of the Upper Atmosphere Has Been Gained by Various Methods. Man's first knowledge of the atmosphere above sea level was doubtless gained by observations made from hills and mountains. By watching the clouds, too, he became aware that atmospheric conditions at an elevation of even a few hundred feet might be different from those on the ground. On one occasion a boy, while lazily lying on his back and looking up into the clear sky, was able to distinguish three crosscurrents of air by the direction in which the cottonwood seeds were being carried. Certain aspects of the air, especially the temperature relations, however, have been found to be quite different near land elevations from those that prevail in open regions, where the air is unaffected by surface conditions. For this reason other means of study were sought.

Special kites carrying sets of small meteorological instruments were employed by early observers. These were limited in their use and were superseded by the balloon and the airplane. Observations by airplanes up to a height of from 17,000 to 20,000 feet have been made from many weather stations. By this method data have been obtained at a height of 40,000 feet or more. Flights at this elevation, however, involve considerable expense and time; and special clothing must be provided to withstand the low temperatures, and oxygen tanks to supply the deficiency of oxygen.

Manned balloons have on special occasions considerably exceeded the height attained by airplanes. The *Explorer II*, bearing Captain Albert Stevens and Captain Orville Anderson sealed in a light magnesium-alloy gondola, reached a record altitude of 72,395 feet on Armistice Day, 1935. This historic balloon carried almost every sort of meteorological instrument imaginable. In addition, many different kinds of data, from those about temperature to data about the effect of cosmic rays on a vial of fruit flies, were obtained. Even a spore trap was opened just after the balloon reached its highest point to determine whether or not these reproductive bodies reached such elevations. Moreover, the two men were in constant communication with ground parties at New York City and Washington, D.C., who had helped to prepare for the flight.

The most valuable and abundant source of information at high elevations, however, has proved to be small, unmanned balloons. They are made of sheet rubber, thin gutta-percha, or cellophane and are inflated with some light gas, such as hydrogen. Many of these *pilot* balloons are carefully observed from the ground with special observational instruments, such as the theodolite. Conclusions regarding the speed and direction of the numerous air currents, as well as pressure, are reached on the basis of these observations. A very great deal of valuable information is obtained in this way. It is obvious, however, that this method is limited to clear weather, when the balloons can be seen.

United States Weather Bureau

An observer following the course of a pilot balloon with the aid of a theodolite

To overcome this difficulty and to secure more adequate information a battery of featherweight, self-recording meteorological instruments has been devised for use with unmanned balloons. As the inflated bag rises, the outside pressure grows less, and the expanding gas on the inside finally bursts the bag. The instruments, often suspended by a second balloon, which acts as a parachute, slowly drift back to the earth. By varying the gas in the carrying balloon as to amount and composition, and the walls of the bag as to material and thickness, different altitudes are reached. Sometimes the instruments are carried down by the ruptured bag itself. It is obvious that the great difficulty here is to recover the instruments, which often drift long distances, especially in windy weather. They are always accompanied by a card giving the address of the station, together with explicit directions as to shipment, and requesting the finder to return them. In addition to the instruments, vacuum glass tubes so designed that an attenuated point in the glass will automatically break and reseal itself when a certain reduced pressure is encountered are sent up to obtain samples of the upper air. Balloons equipped in this manner are called *sounding* balloons.

Hauer, from United States Department of Agriculture

The sound signals from a rising radiosonde are picked up by the receiving set at a ground station

A superregenerative radio receiver, equipped with the necessary dials and earphones for tuning, is electrically connected to an electronic frequency meter (left top center), from which readings of varying temperature and humidity at known altitudes may be noted. The recorder in the panel at the right, operated by a photoelectric cell, graphs the variations in temperature and humidity. The distances between the series of dashes that represent temperature and humidity and the reference dashes that form a vertical line give weather observers the data they need in computing temperature and pressure at the different altitudes reached by the radiosonde. The sequence of the dashes denotes pressure; their spacing denotes time

Within the past few years sounding balloons have been equipped with a tiny set of robot radio-transmitting equipment. In fact, except for special purposes, such as obtaining air samples from the upper atmosphere, these instruments are very rapidly replacing the older type altogether. These diminutive radio sets send back to the station radio signals which indicate the temperature, pressure, and humidity of the air strata through which they pass as they ascend. Recently the United States Weather Bureau has christened these featherweight radio weather reporters *radiosondes*, from the French *sonde*, meaning "sounding" (that is, measurement of depth). A recent radiosonde also reports the direction and velocity of the wind and, through the use of a photoelectric-cell attachment, indicates in addition the presence of clouds and their thickness.

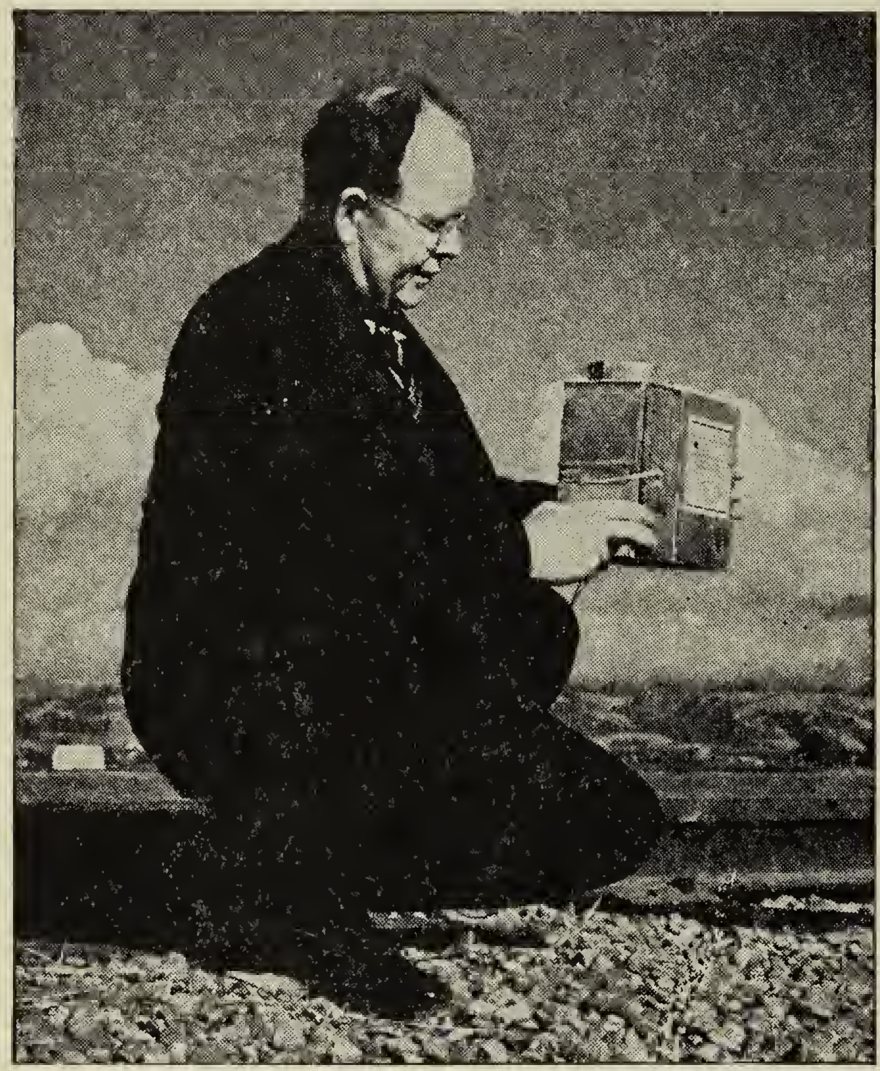
An idea of the size and compactness of the radiosonde may be gained from the dimensions given by A. E. Bent, who devised a five-meter wave transmitter at the Blue Hill Observatory in Massachusetts. His instrument was only $8\frac{1}{2} \times 5\frac{3}{8} \times 4$ inches and weighed exactly one pound. Atmospheric reports of the character described from altitudes of over 100,000 feet have been obtained by Curtiss of the National Bureau of Standards at Washington, D.C. The *Explorer II* balloon flight cost about $100,000; but Dr. Johnson, who has been experimenting with radiosonde balloons at Swarthmore College, estimates the cost of a recent flight of a radiosonde balloon as $25, and this includes the short-wave radio-transmitter mechanism used to send back to his laboratory the stratosphere information.

Altogether there are still many more pilot balloons used by weather observers than any other kind. For this reason they are yet, and will probably continue to be for a while, one of the mainstays of the various weather-station meteorologists. At certain places groups of them are released and observed almost every day in the year. They are reported to have penetrated the atmosphere to the extreme height of over 127,000 feet. This is a little more than 24 miles, or over four times the height of Mt. Everest.

For altitudes beyond the reach of pilot and sounding balloons indirect methods of investigation are resorted to. We have said that for some time the approximately constant temperature of the stratosphere was believed to extend up indefinitely. This belief was first seriously questioned on the basis of the observation of meteors. From the brightness of these incandescent falling bodies it seemed that the temperature must rise again above the stratosphere.

In connection with this problem of atmospheric conditions above the stratosphere, data obtained from studies on sound were introduced. The idea that the air above the stratosphere might be warm was supported by observations made on sound heard at a great distance from its source. When a large explosion occurs, the sound is heard for many miles around, but not at such distances as might be expected. This result arises from the fact that sound travels faster in warm air than in cold. Consequently sound waves travel faster in the warmer air next to the earth's surface than in the cooler air above. Hence the lower part of a wave, near the ground, moves faster and tends to bend the wave up and thus deflect it out into space.

This bending of sound waves upward is well substantiated by the fact that a loud sound emanating from a point in a wide valley is often heard more distinctly on the tops of the more distant surrounding hills than it is at less remote points on the floor of the valley. In the case of very loud explosions it has been found that the sound cannot be heard for a distance of more than from twenty to thirty miles around the explosion. Strangely enough, however, the sound can be heard again very much farther away, perhaps a hundred miles from the explosion, and often as a fairly loud sound. This result has been noted frequently by British physicists, who are taking the lead in long-range sound studies.



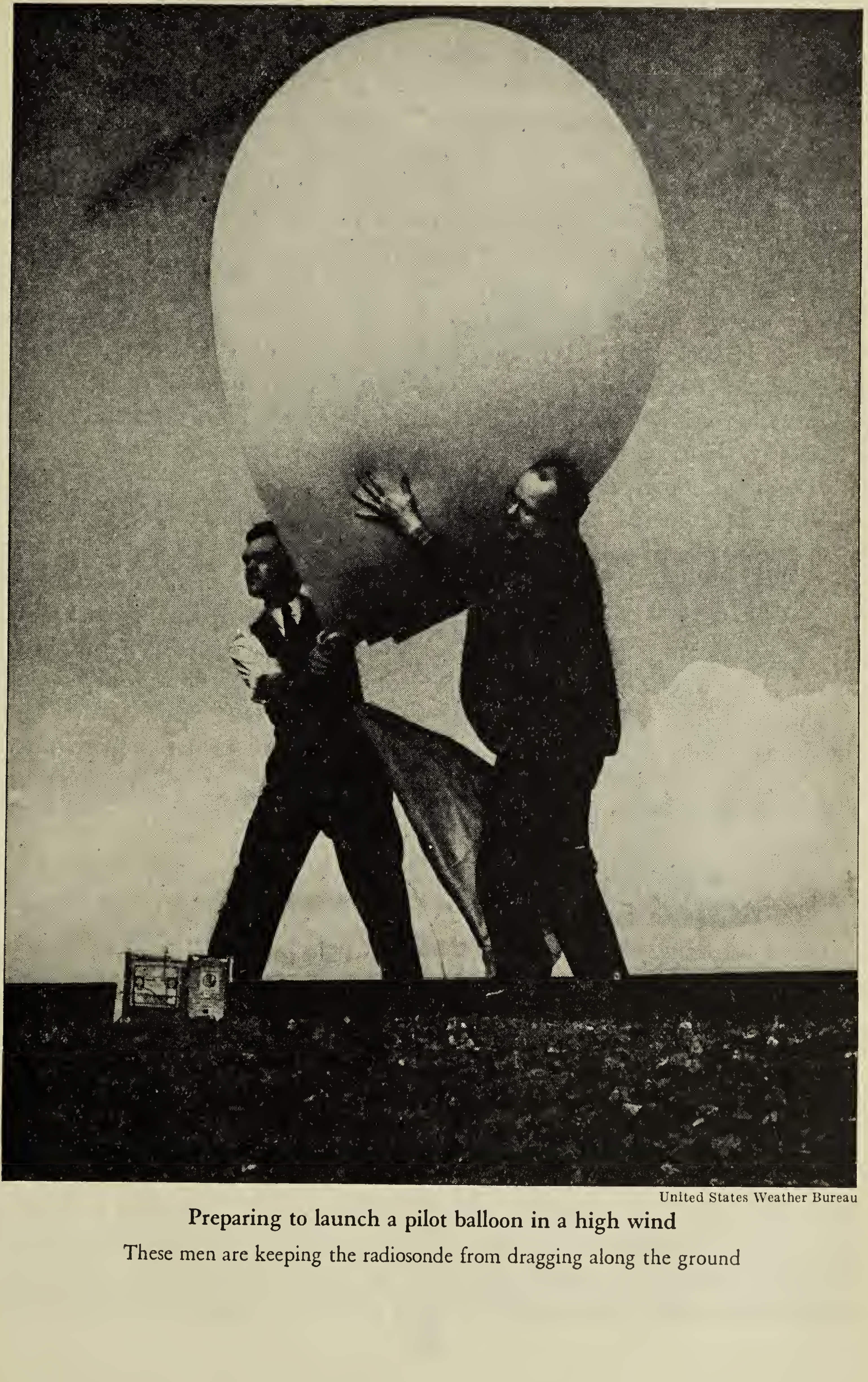
United States Weather Bureau

A radiosonde

Moreover, these sound waves which are heard at a great distance are found sometimes to take as much as two minutes longer to reach that distance than they would have taken had they traveled horizontally along the earth's surface. From this fact and the further fact that they are not heard at intermediate distances, it seems clear that these sound waves must have traveled up into the upper atmosphere and then have been deflected back again toward the earth.

This result was very puzzling until Dr. Whipple pointed out that if at great heights the temperature rose again, as was suggested by the observation of meteors, then the sound waves would be bent downward on entering this upper, warmer air stratum and would thus be deflected back toward the earth by the same factors that deflected them away from the earth at the beginning.

Dr. E. O. Hulbert of the United States Naval Research Laboratory believes, from the effect of these upper air levels on radio transmission and reception, that the "best agreement between the radio facts and the theoretical calculations found [is obtained] if the temperature of these levels is taken to be rather warm, above 300° Kelvin." Three hundred degrees Kelvin corresponds to 80.6° F. Dr. Charles P. Olivier, on the basis of meteoric calculations, estimates that winds with a velocity of 200 miles an hour may



United States Weather Bureau

Preparing to launch a pilot balloon in a high wind

These men are keeping the radiosonde from dragging along the ground blow in this upper atmospheric region—a condition that could not possibly exist without high temperatures.

Cause of Warmth at Great Heights. Radiant energy from the sun is not warm. Visible light can affect temperature only when it is absorbed by water, dust, or other particles in the air and transformed into heat. The same effect occurs when it passes through the atmosphere and strikes the earth and objects at the surface of the earth. At a level forty miles or more above the earth's surface, however, these factors are either not present at all or not present in sufficient quantity to affect temperature. Consequently the heat at these upper levels must be due to some other kind of absorption. Dobson, a meteorologist at the University of Oxford, believes it can be accounted for on the basis of ultraviolet-light absorption by oxygen and ozone. Ozone is a triatomic molecule of oxygen, expressed chemically as O_3.

The ozone component of the whole atmosphere is on an average not great. It has been estimated that if all the ozone from a complete vertical column of the atmosphere could be extracted and be measured at sea level, it would on an average make a layer just about three millimeters thick. But although limited in quantity, it is a most important component of the upper air. It acts as a screen in that it strongly absorbs the ultraviolet part of the sunlight in the lower levels of the superstratosphere region. Indeed, were it not for this absorption, it is believed that life on the earth, as we know it, would be impossible. The ultraviolet rays would blister human beings unmercifully. It is this type of absorption, then, that is considered to be the causative factor behind the high temperatures at these lofty elevations. Just how high these warm layers extend is not known.

The Atmospheric Strata in Profile. At this point it will be helpful to make a survey, so far as possible, of the atmosphere. The lower stratum is called the *troposphere*, or turning sphere, because its parts are always in a state of turbulence. If we liken the layers of the atmosphere to the stories of a building, as Dr. McAdie does, this story is approximately seven miles high, and, like the basement floor of many modern buildings, with their power and other service plants, is one of confusion and turmoil. Through this lower story the heat from the earth causes convection and wind currents to rise upward, or cut crosswise, or twist and turn in strange ways. If these currents are mild, gentle breezes stir; if more rapid, winds blow; and when they are extremely violent, hurricanes and tornadoes devastate the earth. In this story, too, vapor drifts, clouds form, and thunder crashes. Gradually changing temperatures result in seasonal progressions, while the sudden fluctuating and irregular changes produce a range of weather from the clearest sunshine to the cloudiest rainy day. This troposphere is not of equal depth the world over, but bulges up over the equator and is crowded down round the poles.

Above this lower story of sunshine, tempest, and storm is a second floor called the stratosphere or the isothermal region. Either term is appropriate, depending on one's point of view. The first indicates that there are no large vertical temperature gradients, as in the troposphere; the second indicates that the region is one of relatively uniform temperature. The stratosphere is estimated to extend from the troposphere to a height of about thirty or thirty-five miles. This gives it a depth of from twenty-five to thirty miles. The stratospheric layer was first discovered in 1898 by a Frenchman who sent up balloons carrying thermometers. When the balloons reached a certain height, he found that the temperature became practically constant. At first he suspected that the thermometers which he was using were faulty and unreliable. When others were substituted, the results were the same. Soon observers in different countries, stimulated by the report of these findings, investigated and got similar readings. In this way the existence of the stratosphere was established in a short time. The detailed explanation of why the stratosphere remains at the same temperature is too complicated to attempt here; but it depends principally upon the fact that as air rises from near the earth, it cools by expansion and radiation, and whenever this cooling reaches the point where the heat absorption is balanced by radiation, the temperature remains constant and the air ceases to rise.

The stratosphere stands out in sharp contrast to the troposphere. There are few clouds. Aviators who ascend into it testify to its low temperatures and reduced oxygen supply. The floor of the stratosphere is generally the upper limit of vapor clouds. Occasionally thin cloudlike bodies appear in this region, but their nature is uncertain.

Above the stratosphere man cannot be so certain of his conclusions regarding the atmosphere. There is much less direct evidence. Consequently statements must be provisional and subject to revision as new evidence accumulates. From the evidence given by the movement of meteors and sound waves, however, we have found that above the stratosphere a second heat belt doubtless does exist. Moreover, above the stratosphere there are other layers, often spoken of as radio ceilings.

But the theory of radio ceilings must be verified, if possible, and scientists attacked the problem in different ways. One of the most fruitful methods proved to be the use of reflected radio waves much as reflected sound waves are used to determine the depth of the ocean. It has been found that a radio wave will be stopped in its progress and reflected back again whenever it encounters a layer of air sufficiently ionized to possess enough electrons. Such a layer is called an *ionosphere.*[1] The number of electrons required is determined largely by the length of the wave. Since shorter waves have more energy, they will be more penetrating, and it will require a greater density of atmospheric electrons to reflect them. Thus a radio wave of 900 kilocycles per second will be reflected when the electron density becomes 10,000 per cubic centimeter; but a 9000-kilocycle wave will travel until it encounters an electron density of 1,000,000 electrons per cubic centimeter before it is turned back.

In making these tests a radio transmitter is arranged to send out a short pulse, say of $\frac{1}{1000}$ second duration, of radio waves of a desired length. This pulse is recorded by a near-by receiver. This receiver may be either in the same room with the transmitter or within a distance of a few miles. The single pulse transmitted, however, usually produces two or more pulses in the receiver. One of these is due to waves that pass directly from the transmitter (ground wave) to the receiver. The other pulse is caused by waves that have traveled up to the ionosphere and have been reflected back to the earth. In reality, they are the "echoes" of waves that originally proceeded out skyward from the transmitter. Consequently one half the time difference between the reception of the ground pulse and the echo, multiplied by the velocity of the radio wave, as nearly as that can be determined under the existing conditions, will give the approximate height of the ionized air stratum from which reflection occurred.

The radio frequencies employed usually range from 500 to 16,000 kilocycles per second. In other words, the waves range from about 598 m down to 18 m in length. In making a series of readings the transmitted pulse is begun on the long wave, and the echo observation is recorded. The frequency is now stepped up; and when the wave becomes short enough, it penetrates the first ceiling and hence is no longer reflected back from it. If there is another region of ionization higher with a sufficient electron density to turn this higher-frequency wave back, then it becomes the ceiling for that particular wave length. Now the frequency is again stepped up, and penetration of this second ceiling occurs. Finally, the frequency becomes so high and the resultant waves become so short that all regions of ionization are penetrated, and no more echoes occur. In this way the heights and densities of all regions of ionization are approximately charted and recorded.

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[1] For the discussion of ionospheric conditions the writer is greatly indebted to Dr. E. O. Hulbert of the United States Naval Research Laboratory. Much of the material on the following pages has been taken directly from his article "The Ionosphere," *Scientific Monthly,* Vol. 48, pp. 421–430, 1939.

It must always be remembered, however, that electron density is conditioned by many factors. Among these are sunspot intensity, time of day, density of air, latitude, and season.

At the present time there are seven ionosphere stations either already recording results or preparing to do so. Four of them are located north of the equator and three of them south of the equator. Several minutes are required for the transmitter to sweep through the frequency range used and for the echoes to be recorded. In the most recently equipped stations, however, four or even more complete readings of this character may be made in an hour.

Since the ionization in the ionosphere regions is so greatly affected by the sunlight, it seems evident to students of this problem that the cause of the free ions is solar ultraviolet rays. It is obvious that for every electron liberated by atomic disruption a positively charged ion is produced. These oppositely charged ions tend to reunite with alacrity; but at any instant there is always an excess of ions, and it is these which constitute the ionosphere.

Radio fade-outs, which have been known to occur over large areas of the earth for from several minutes to an hour, are connected with ionospheric changes. At Mt. Wilson it has been noted that disruption of radio communication often occurs simultaneously with unusually bright hydrogen eruptions on the surface of the sun. Ionospheric observations have shown that the fade-out in turn was caused by a sudden increase of ionization at some level.

Another phenomenon of the upper atmosphere is the *aurora borealis*, or northern lights. Admiral Byrd's expedition to Antarctica has shown conclusively that this display is not limited to the northern regions, since most gorgeous manifestations occur also in south-polar areas. These southern displays are called *aurora australis.*

Recent investigations indicate that the auroras are caused by electrical disturbances in the very high upper air. Sunspot maxima are always accompanied by an increase in the frequency and brightness of the auroral displays. The direct cause is not known, but a widely accepted theory attributes them to the effect of electrons expelled from the sun with great velocity. As these, influenced by the earth's magnetic poles, enter the upper terrestrial atmosphere, they excite the rarefied gases in such a way as to produce a glow. The effect is very similar to the display in a Crookes tube or a neon sign.

The average altitude of the auroras has been estimated as 100 miles, although they have been observed as high as 400 or 500 miles and more. The extreme limits of the upper atmosphere are not known. It doubtless thins out to an imperceptible degree. But an appreciable molecular density probably does not extend much beyond the limit of the auroras.

A Hydrosphere Developed upon the Earth. Water is the most useful of all liquids found on the earth. Without it life could not exist for a single day. A large part of the energy-giving food of plants consists of hydrogen obtained from water. Through the plant it later becomes a part of the flesh of animals. So intimate is its relation to life that even that strange living substance, protoplasm itself, is largely water. Everything that enters or moves about in the bodies of either animals or plants is dissolved in water. Practically all the waste products thrown off in the form of true excretions move out of the body in a liquid form, with water as the solvent. As we have already found, through the latent heat of vaporization, water also assists various species of animals to regulate their temperatures through the physiological processes of sweating or perspiration. For these reasons plants and animals must all constantly refresh themselves at the life-giving streams of water either held in the soil, or flowing over its surface, or filling the subterranean recesses. If water, then, is so important, how did it come to be in such abundance on the earth?

Certain Theories Have Been Propounded to Explain the Existence of the Hydrosphere. There are differences of opinion as to how the great mass of water on the earth and in the air which we call the hydrosphere (Greek *hydor*, "water," and *sphaira*, "sphere") came to be formed.

Various theories have been proposed; but perhaps the best one is that when the earth was yet small but had pulled in enough planetesimal material, in a more or less condensed form, about its nucleus, it began to have sufficient gravity to gather molecules of atmospheric gases, among them being much water vapor. Moreover, as the planetesimal material pulled in by the force of gravity accumulated, it settled down and, owing to radioactivity and compression produced by the pressure of its own weight, tended to heat the growing earth's interior. At that time doubtless much water was also held in this early original earth material. But as heat and pressure were applied, water escaped in the form of vapor and became a constantly increasing part of the atmosphere. In these early periods it is also probable that a very vital and extensive volcanic action was taking place, from the craters of which great quantities of steam and water vapor were expelled. If this explanation be true, then it may be seen that the hydrosphere, like Topsy, "just growed." Moreover, it would seem to imply that in that early period, millions of years ago, the earth was enveloped in clouds and fogs similar to those which seem to surround the planet Venus today.

The Accumulation of Large Quantities of Water in Certain Areas Has Formed Oceans. Perhaps because of the unequal aggregation of the planetesimal matter that originally formed the more solid parts of the earth, growth, or increase of size, was not equal at all points on the earth. If Chamberlin's theory be true, it is probable that the earth's surface always had some areas raised above others. Then when the water of the atmosphere became so abundant as to condense and fall in the form of rain, it collected into the lower places, which now form the main ocean beds. Subsequently, as the planetesimal matter continued to fall, that which fell into the ocean was protected from weathering; but that added to the already existing land was leached out by weathering, and its heavier portions were carried down to the sea, as will be more fully developed in a later chapter. This augmented weight further depressed the bed of the growing oceans and made them deeper. Water continued to accumulate there through the long aeons of time, and in this manner the vast seas and oceans were formed.

The Hydrosphere Is Very Extensive. The extent of the hydrosphere, exclusive of the water of the atmosphere, is much greater than the land. The total surface of the globe is approximately 197,000,000 square miles. Of this approximately 71 per cent, or 140,000,000 square miles, is water. The sea is not of uniform depth. Indeed, there is more irregularity of surface at the bottom of the sea than on the land. The extremes of land elevation range from a little below sea level (the Dead Sea and points in Death Valley) to 29,140 feet on the top of Mt. Everest in the Himalayas. The known depth of the sea, however, ranges from the shore line to a point 35,433 feet below the surface found in the Pacific Ocean just off the coast of the Philippine Islands. At the deepest point, then, the whole of Mt. Everest could be lowered into the sea. When it had finally settled down on the bottom, its summit would be over a mile below the surface of the water. If the bottom of the sea could all be leveled down and the water spread out evenly over it, the average depth of this ponderous hydrosphere would be twelve thousand feet.

The Cyclic Action of Water Is Constantly Increasing the Salinity of the Ocean. Modern geologists tell us that the sea is salty because of the prolonged and continuous cyclic movement of vast amounts of water. Rain or snow falling on the land areas dissolves out of the soil a tiny load of soluble materials and carries it down to the sea. Pumped up by the sun's rays in the form of vapor, the water again takes its flight back to the land, leaving its small residue of dissolved materials behind to accumulate in the sea. Some salt was also dissolved from the vast beds upon which the ocean originally stood.

Some idea of the vast resources which reside in marine water may be obtained from the following adapted table of *elemental reserves in the ocean* as furnished by Lathe[1] of the Canadian Research Council:

Element	Tons per Cubic Mile	Element	Tons per Cubic Mile
Chlorine	90,000,000	Potassium . . .	3,300,000
Sodium	53,000,000	Calcium	2,400,000
Magnesium . .	5,700,000	Bromine	310,000
Sulfur	4,300,000	Iodine	200

These elements for the most part appear in their combined form, of which sodium chloride is obviously by far the most abundant. Sea water contains on an average about three and a half pounds of salty material to every hundred pounds of water.

The salinity of the oceans differs somewhat at different places. Where large rivers are pouring a constant stream of fresh water into the sea or where evaporation is low, the water is less salty. Where evaporation is high, as in the Red Sea, the salt content exceeds the average. Quiet waters where arms of the sea extend back into the land, and are thus protected from the mixing effects of current and wave, tend to become much more saline than the waters of the open sea.

It is probable that the rich salt deposits now mined commercially were deposited for the most part in great lagoons periodically filled from the ocean and then concentrated through evaporation. In New York State alone these salt beds are from nine thousand to ten thousand square miles in extent. Salt layers are often interstratified with deposits of shale. Some of these single salt layers may reach a thickness of from forty to eighty feet.

Temperature and Pressure Change with Increased Ocean Depth. As a mass of water, the sea is surprisingly cold. Penetrating heat rays are all absorbed within a depth of fifteen hundred feet, so that even in the tropics the surface layer of warm water is relatively thin. Cold, denser waters from the frigid regions tend to slip in slowly under the warmer, lighter tropical waters and gradually force them poleward and so equalize the temperature.

While there is some diversity in the temperature of the surface water in different localities over the earth, the temperature of the water at any one place is surprisingly uniform throughout the year. The self-regulatory effect of evaporation contributes largely to this end. As the surface water gets warm, evaporation speeds up, and this, through the absorption of heat of vaporization, tends to check the rise in temperature; if the temperature falls,

[1] Frank E. Lathe, "World Natural Resources," *Science*, Vol. 88, p. 339. (1938)

fog forms in the air, thereby releasing heat. The fog also acts as a blanket to hold the heat in and increase the temperature of the surface water.

At a depth of 300 feet it is doubtful whether the temperature changes more than 2° F from one year's end to the next. Below 600 feet there is no evidence of any annual temperature change whatever. Sir John Murray, a noted Canadian scientist, estimated that 87 per cent of the whole ocean lying below a depth of 1500 feet has a temperature under 40° F. Ooze brought up from great depths by dredges is almost ice-cold, and it is a well-established fact that the temperature of the deep ocean constantly hovers round the freezing point of water.

Owing to the weight of the water above, ocean pressure mounts up enormously with depth. The force exerted by it has been computed to be two and one-half tons per square inch at a depth of fifteen thousand feet. In the deepest parts of the ocean it is twice that. Blocks of wood carried to great depths by being attached to weighted sounding lines have the woody tissues so forcibly infiltrated with sea water that when they are brought to the surface again they sink in fresh water. Evacuated glass cylinders and even brass cylinders were sent down into the lower ocean depths by the *Challenger* expedition. When they were suddenly subjected to these enormous pressures they collapsed as if hit by a trip hammer.

Yet under these unusual conditions of pressure marine fishes live with impunity. Because the hydrostatic force on the outside and the inside of the tissues is equalized, they suffer no more discomfort than ordinary animals at sea level. Indeed, the danger to these deep-sea fish is that of "falling upward" in the water. As they rise above the level to which they have become adapted, owing to diminished pressure on the outside, their swimming bladders tend to expand. This increases their buoyancy, which becomes so great, if they get too far up, that they are shot upward toward the surface with increasing velocity. Finally, the inequality of force becomes so great that they literally explode, the tissues being ruptured and the eyes being forced out of the sockets.

Thomson has summarized the importance of the sea in the following paragraph:

> In many ways the sea makes the earth more livable. It absorbs the heat of the "tropical sun" and distributes it far and wide. It tempers the great heat by currents of ice cooled water from the Poles, and by cold water rising from the wintry depths. It is the cradle of many of the winds which do so much for good as well as ill. It is the central depot in the incalculably important circulation of water; it is the beginning and the end of rivers. Its give and take—absorption and restoration—of at-

mospheric gases makes for uniformity in the composition of the air. It is the universal clearing house, the universal cleanser. In the sea all waste is reduced to its common denominator, and the results of the wear and tear of the earth are laid down in deposits which *might* again become rocks. Finally, the sea yields man a rich harvest; it has always been one of his great schools; and it binds together much more than it separates.[1]

Questions for Study

1. Why is the moon believed to be a desolate place devoid of life?
2. In what ways do the hydrosphere, the lithosphere (the solid part of the earth), and the atmosphere contribute to conditions which make life on the earth possible?
3. It is said that the automobile engine loses some of its power when passing from a lower region to one of appreciably higher altitude. How would you attempt to explain this effect?
4. Why is it of importance to man to be apprised of significant atmospheric changes by accurate instruments which measure them?
5. In what ways does the composition of the troposphere contribute to the life of all living things?
6. How do changes in temperature affect the atmosphere?
7. How would you explain the fact that the character of plant life changes as one travels up the slope of a mountain?
8. What are some of the effects which weather conditions have upon the physiology and activities of man?
9. How can you account for the beautiful sunsets which often occur?
10. How do you account for the apparently greater size of a rising or setting sun or moon?
11. Why are the sunsets amid broken clouds often fiery red in color?
12. How can the passage of a radio program around the earth be explained when the waves themselves travel in straight lines?
13. What is the most recent theory as to the cause of the auroras?
14. How would you explain the sudden fading of radio sound?
15. Why is radio reception better in winter than in summer?
16. Of what importance to man is the fact that large portions of the earth's surface are covered with water?
17. How can you account for the fact that the coast of northwest Canada has a very mild climate when it is far north of the equator?
18. How would you explain the fact that the South Temperate Zone has a more equable climate than the North Temperate Zone?

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[1] J. A. Thomson, *The Outline of Science*, Vol. IV, p. 975. By permission, George Newnes, Ltd., publishers.

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CHAPTER TWENTY-SIX

Weather Proceeds from Atmospheric Conditions

The Inclination of the Earth Produces Seasonal Effects That Greatly Modify Weather. An examination of the earth as a planet reveals that its polar axis is not perpendicular to the plane of its orbit. It intersects it at an angle of about 23½ degrees from the perpendicular. From the point of view of life on the earth this tilted position of the globe is an important matter. It affects the climate profoundly. It is also a major factor in determining the weather of any given locality. The atmospheric conditions in January at St. Louis, Missouri, let us say, are quite different from those in July; the weather of the late spring there is also of a different character from that of November. Because of its great influence on weather, aside from its climatic effects, we must give some attention now to the inclination of the earth.

If the earth's axis were perpendicular to the plane of its orbit, the sun's rays would be approximately vertical over the equator at all times, and the equatorial regions would have the same hot tropical climate from one year's end to the next. As one passed from the equator toward the poles, he would traverse regions of increasingly cooler climate both above and below the equator, and finally he would encounter extremely rigorous frigid zones around the poles. These frigid zones, too, would probably have a much greater area and a much lower summer temperature than now prevail there.

This condition probably would mean that the portions of the earth capable of supporting a luxuriant vegetation, which directly or indirectly furnishes food for animals, would be much more limited in area. Indeed, in the higher intermediate and polar zones of both the Northern and the Southern Hemisphere there are millions of acres, now supporting a fairly generous amount of life, both plant and animal, that would be nothing but barren, frozen wastes if the earth's axis did not incline from the perpendicular position.

But since the earth's axis is inclined from the perpendicular to its orbit, the north pole is kept pointing approximately toward the polar star as the earth travels its path about the sun. Consequently the vertical rays of the sun slowly shift from south to north and then back again throughout the year. Apparently the sun moves its position with reference to the earth. But it is the earth that moves instead of the sun, which is one more evidence of the relative nature of motion. The perpendicular rays of the sun cross the equator twice in the course of the year, and these dates mark the vernal and autumnal equinoxes, occurring, respectively, about March 21 and September 22. Were the earth not inclined, the sun would always assume the same position with reference to the earth that it holds on these dates; but during the spring months in the Northern Hemisphere the point at which the sun's rays are perpendicular to the earth gradually creeps northward until June 21, when it reaches the northern limit of its range. This imaginary line round the earth is called the tropic of Cancer, and is 23½ degrees north of the equator. During this season the sun's rays in these latitudes are more intense not only because of their perpendicularity but also because they have to pass through a very much thinner layer of air. The high degree of insolation, or heating effect of the sun, received in this way stimulates a period of great activity on the part of plants and animals.

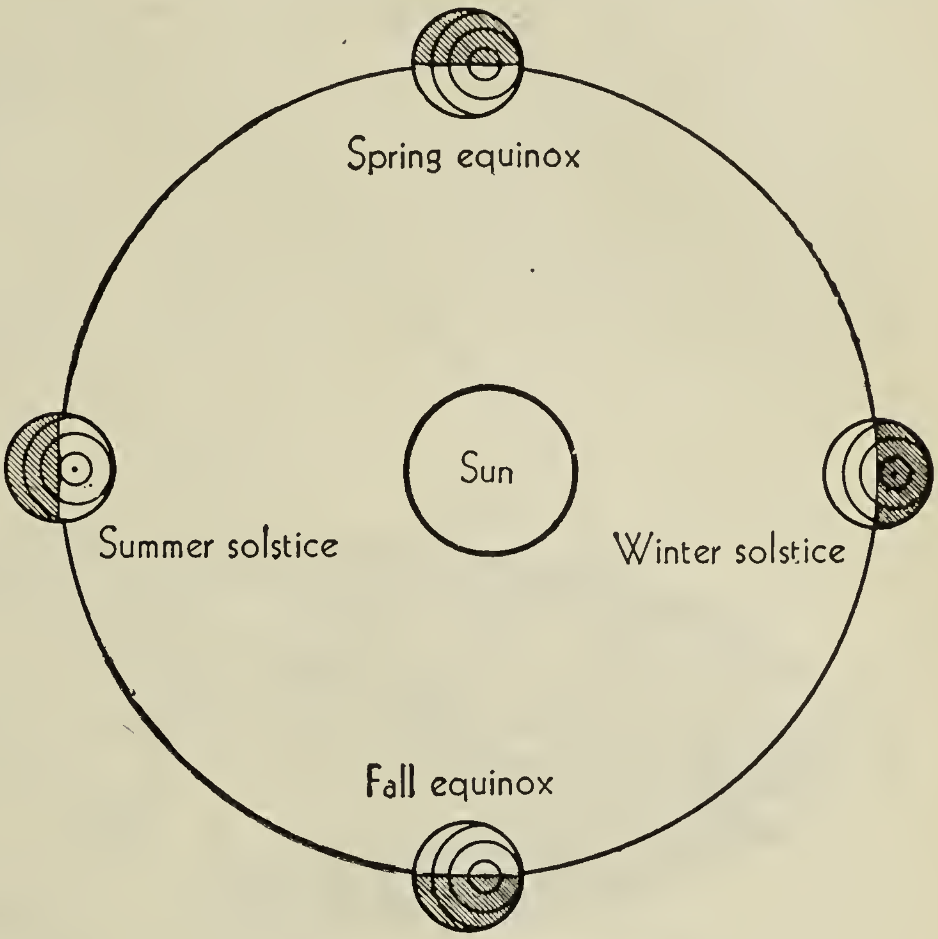

Diagram to show the relative position of the earth and the sun at the beginning of each of the four seasons

During the winter months in the Northern Hemisphere the position of the sun with reference to the earth is reversed and the Southern Hemisphere is having its summer season. The winter solstice occurs December 21, which marks the date upon which the perpendicular rays of the sun reach their extreme southernmost point. This line marks the tropic of Capricorn, which, like the tropic of Cancer, lies 23½ degrees from the equator. Life of all kinds in the Southern Hemisphere now thrives, while that in the Northern Hemisphere is relatively dormant.

The polar zones extend 23½ degrees from the poles, which, with a torrid zone 47 degrees wide, leaves each intermediate zone approximately 43 degrees in width. It is in these intermediate-zone areas of the earth that the enterprising civilizations of the world flourish.

It may be easily seen that this apparent shift of the sun from the tropic of Cancer to the tropic of Capricorn and back again is of prime importance in determining climate. It is also one of the major factors, as has been stated, in producing that series of changing atmospheric conditions called weather. With this clear understanding, then, let us disregard the climatic effects that might be discussed in this chapter and give our attention wholly to the matter of weather.

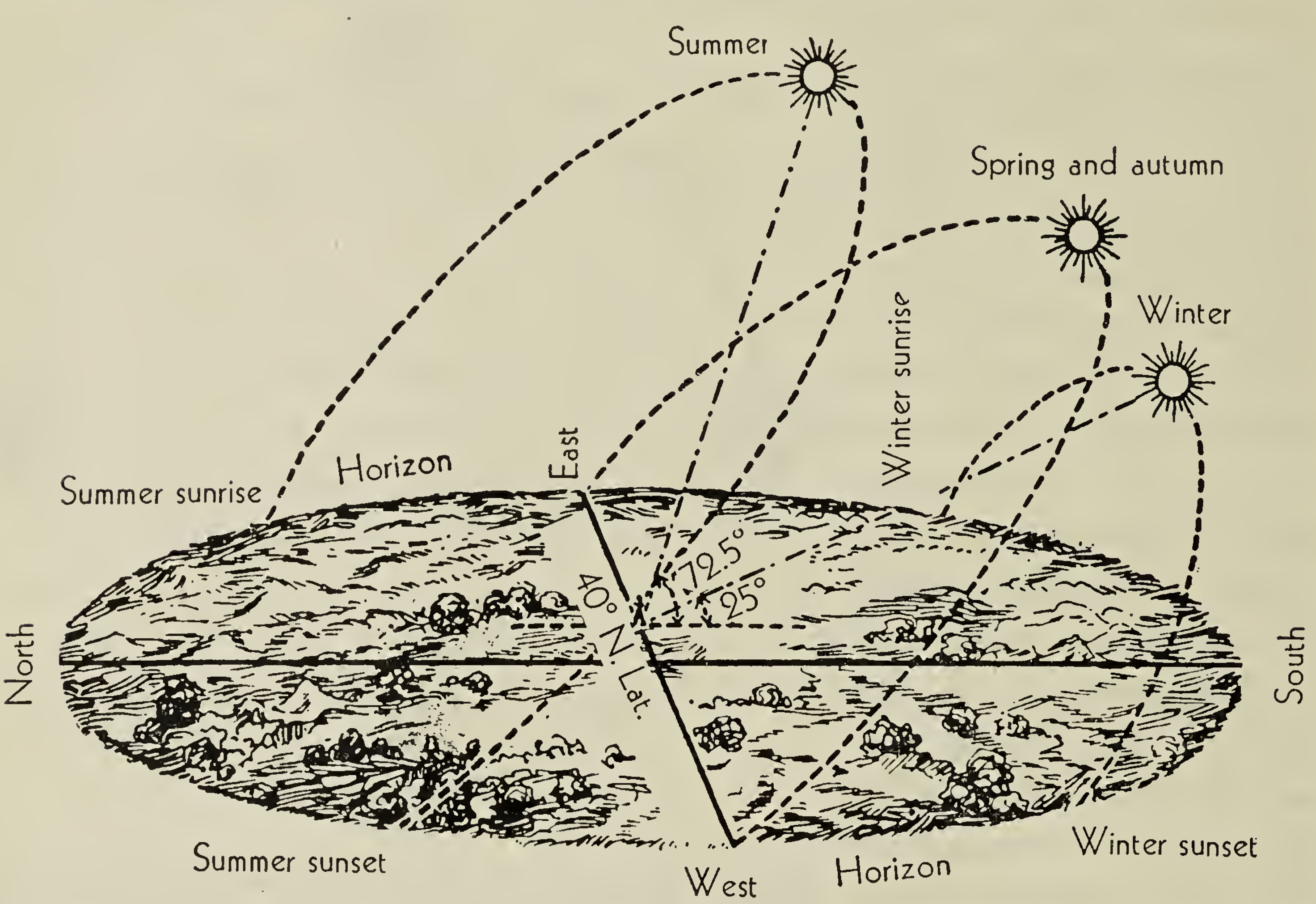

Diagram to show the apparent shift of the sun in the Northern Hemisphere from winter to summer[1]

Many Superstitions regarding the Weather Are Extant. There are, perhaps, few manifestations of natural phenomena about which more superstitions and vagaries have grown up than about the weather. Because atmospheric conditions affect man's affairs so directly and vitally every day, he has ever been on the lookout for signs by which he could foretell impending changes. He recognized that if he could just get the clue as to how the weather was going to behave he might either enhance his profit and pleasure or escape disappointment and financial disaster. Naturally, then, every observing individual had his favorite weather signs, and their number became legion.

It is only in comparatively recent times that man has come to recognize the same inexorable law of cause and effect working in the atmosphere to produce weather which works in nature everywhere to create changes. The wise men of old apparently recognized the reign of natural law in connection with weather, but the general acceptance of this principle has had a long and stony road to travel. Indeed, even yet there are some uninformed persons who repose more faith in signs than in conclusions based upon scientific observation. The difference between the scientific and the superstitious point of view was delightfully expressed by the brilliant Aristophanes in a dialogue which, in one of his plays, takes place between Strepsiades, a Greek rustic, and Socrates, the renowned rationalist philosopher. The philosopher had taken the position that weather changes, such as rain, were not produced by the whims of Zeus. The dialogue runs as follows:

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[1] From *Everyday Problems in Science*, by Pieper and Beauchamp. By permission of Scott, Foresman and Company.

Strepsiades

No Zeus up aloft in the sky!
Then you first must explain, who it is sends the rain;
or I really must think you are wrong.

Socrates

Well then, be it known, these [the clouds] send it
alone: I can prove it by arguments strong.
Was there ever a shower seen to fall in an hour when
the sky was all cloudless and blue?
Yet on a fine day, when the Clouds are away,
He might send one, according to you.[1]

Weather is not a vague thing of caprice and uncertainty. Atmospheric changes are often sudden, extremely complicated, and hard to understand. But every day additional information is being collected, and man's knowledge of the air is expanding. In the future we shall know much more about the weather than at present. Meteorologists may become able to predict what the weather will be a week in advance with much more certainty than they are doing it at the present time. But because the atmosphere is a system of mobile gases, there will probably always be unforeseen local disturbances that will modify the weather to some degree.

Weather Is Confined to the Troposphere. The troposphere is the great arena in which the succession of complicated atmospheric conditions called weather takes place. This great shell of the atmosphere is raised around the equator and dips down around the poles, so that its ceiling in cross section looks much like the outline of an eggshell when cut through from end to end.

The principal actors in producing weather within this troposphere are the sun and the gravitational attraction between the earth and the air, with the

[1] Benjamin B. Rogers, *Translation of Aristophanes' Clouds.* By permission, G. Bell and Sons, Ltd.

chief role going to the latter. As Humphreys puts it, "Atmospheric circulation is a gravitational phenomenon, induced and maintained by temperature differences." Although but one two-billionth of the sun's energy strikes the earth, the intensity of this energy and the manner in which it is distributed over the earth are sufficient to keep the atmosphere in a state of more or less constant turmoil.

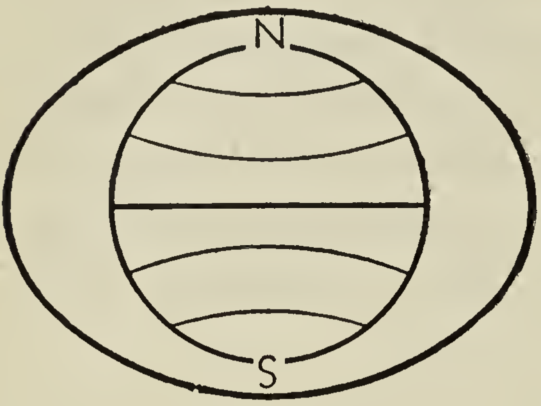

Diagram to illustrate the region of the troposphere

There Is a General Atmospheric Circulation. Primarily because of the unequal heating effects of the sun, the influence of gravity, and the deflecting "force" of the earth's rotation, there may be said to be a general theoretical atmospheric circulation about the globe. Such a general circulation is what one would expect if conditions over the whole earth's surface were uniform. But they are not; for added to the influences already enumerated are others, such as the lack of temperature uniformity with latitude, diversities in the earth's surface due to the irregular distribution of land and water, and differences in land elevation. This complex of influences all interact in a most intricate manner to modify and render intermittent a general air circulation such as is portrayed diagrammatically in the illustration on page 476. Nevertheless, through careful data taken by meteorologists at many places over the globe, we find that not only "pressure and winds are closely related, but also that their distribution may be generalized into a simple system dividing the earth into a few large belts or zones."

Air tends to rise over the warm equatorial regions and flow poleward at higher levels, while air from the poles tends to flow toward the equator at the earth's surface. The actual circulation is not, however, a simple exchange of air between the equator and the poles, but is much complicated, as we have found, by other factors affecting the movement of the winds. Air (or anything else) in moving over the earth tends to deviate from a straight course on account of the earth's rotation. The deflection due to this cause is to the right in the Northern Hemisphere and to the left in the Southern.

One result of the deflection of the winds is that the great mass of air flowing poleward at high levels from the equatorial regions eventually becomes a broad stream of winds blowing in a general west-to-east direction around the globe. The tendency of these winds to return toward the equator because of the so-called "deflecting force of the earth's rotation" leads to a banking up of air at about latitude 30 degrees in both hemispheres, producing a partial belt of high pressure. The belt is not continuous, but is broken up into separate areas of high pressure which vary considerably in magnitude and intensity and which shift north and south to a certain extent with the seasons. The zones of high pressure are known as the horse latitudes. This name has been variously explained. According to the usual account it arose from the fact that in colonial days sailing vessels carrying cargoes of horses were often so delayed in this region in the Northern Hemisphere that some of the animals had to be thrown overboard to save water.

Between the high-pressure zones just described and the equator there is a regular movement of air toward the equator along the surface of the earth. This movement of air constitutes what are known as the trade winds. Owing to the deflecting influence of the earth's rotation they form northeast trades in the Northern Hemisphere and southeast trades in the Southern Hemisphere. In favored locations they are remarkably constant in both direction and velocity, "blowing almost uninterruptedly day and night, winter and summer, with a velocity of 10 to 15 miles per hour." Above these trades and moving in a counterdirection, the upper atmosphere is considered to form the anti-trades. Near the equator, between the two trade-wind systems, is a region of calms or light and variable winds, with abundant clouds and rains, known as the doldrums. Trades and doldrums shift somewhat north and south in the course of the year, following the sun, and give to regions which come under their control successive dry and rainy seasons.

The prevailing westerly winds of the middle latitudes are stronger in the Southern Hemisphere, where they blow mainly over the ocean and are less impeded by friction, than in the Northern Hemisphere; hence the violence of the winds known to mariners as the "brave west winds" in the region called the "roaring forties" (about 40 degrees south latitude).

Within the polar circles the low temperatures increase the density of the air which flows away from the poles near the earth's surface, an effect that is reinforced by the drainage of the air down the glacier slopes of the two polar continents, Greenland and Antarctica.

So the accompanying figure of the general atmospheric circulation (p. 476) must be regarded as a very general picture of that circulation. But it will be convenient and helpful to portray it thus, for by so doing we may form a suitable background upon which to project many variable local air movements and currents which must be brought into the picture.

The General Atmospheric Circulation Is Modified by Many Complicating Influences. If the great air movements already noted were not interfered with in any manner, the earth's weather conditions would be a much

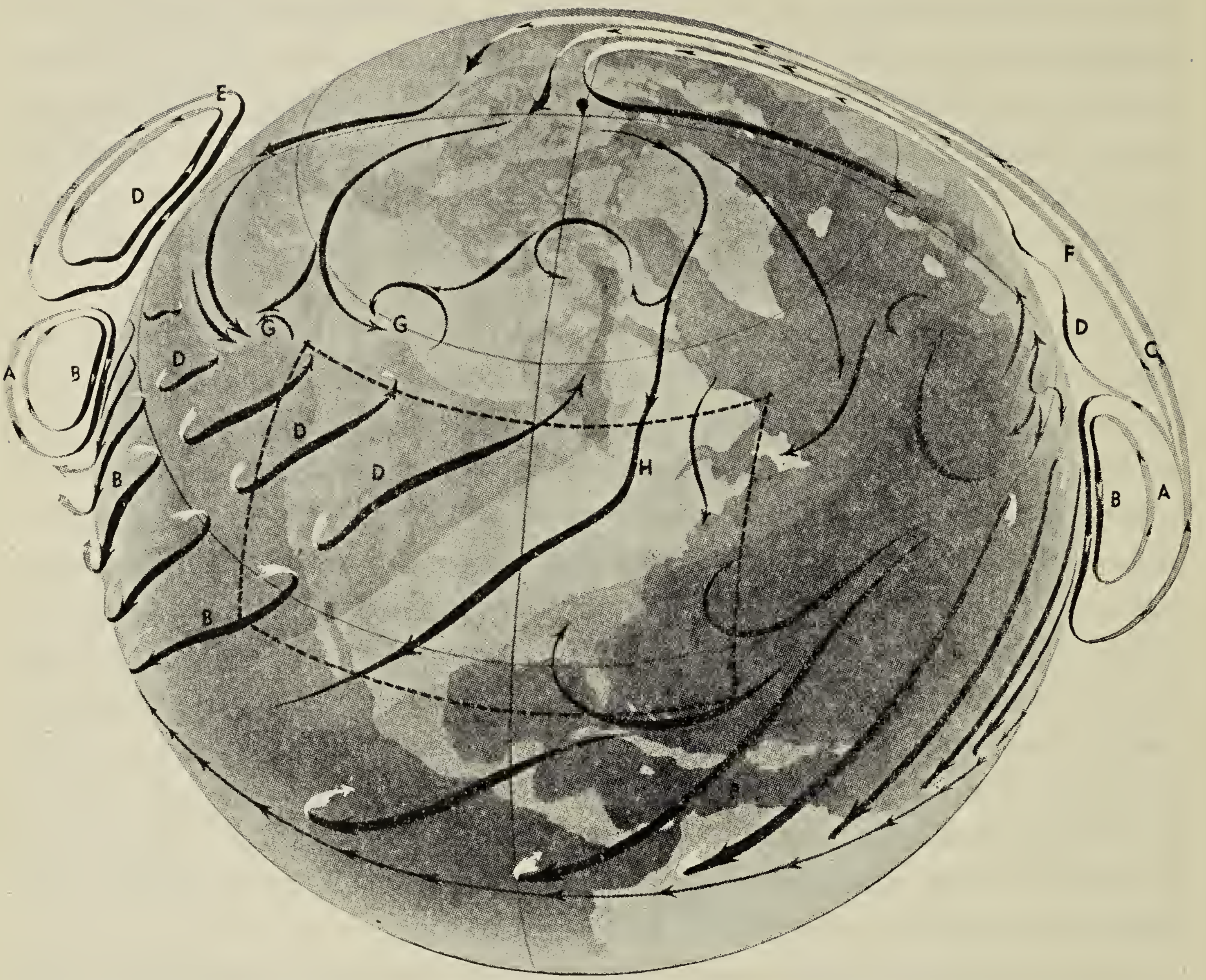

Diagram showing the wind movements in the Northern Hemisphere (adapted from a diagram by V. Bjerknes)

On the left and right the circulation is shown in sections. The arrows on the black ribbons show the direction of the currents. The ribbons change to white as the air mass turns upward. Equatorial air rising out of the doldrums is deflected northward by the earth's rotation. These are the antitrade winds (*A*). Cooled, most of them descend at 30° N. Lat., forming a high-pressure belt, the horse latitudes. Part of them return along the surface to the equator as northeast trade winds (*B*); the rest continues on course at all altitudes as the prevailing westerlies of the middle latitudes. The upper levels of these winds (*C*) generally travel to the poles. The surface winds (*D*) encounter a front of polar air at about 60° N. Lat. and bend aloft. This westerly stream may either double back aloft (*E*) to the horse latitudes or climb the polar front (*F*) and join the upper flow to the pole. Air descending over the pole is deflected by rotation westward. The inflow of tropical air from above is equalized by pushing a frontal barrier south when sufficient mass has been built up. The break usually occurs at the point of a bulging wave in the front (*G*), each wave developing a cyclonic storm. When fully developed, it draws the polar air far to the south, disrupting the normal flow of the westerlies, thus producing cold waves and violent storms in the middle latitudes. The map on page 488 shows the weather in the dotted rectangle under such conditions. (Drawn by Theodore Kautzky. From *Fortune*, April, 1940) simpler matter. But the conditions that modify them, as has been emphasized, are almost legion. About seven tenths of the earth's surface is water, which, partly on account of its high specific heat and partly for other reasons, warms much less by day and cools much less by night than land and has correspondingly less effect in warming and cooling the air above it. The resulting contrasts in temperature between continents and oceans give rise to convective air currents. Moreover, the land area is not evenly distributed, much more of it being in the Northern Hemisphere than in the Southern. The topography is not uniform, but is occupied here and there by flat plains and high mountains. The earth also revolves about the sun, sometimes being three million miles closer to it than at others. Because of its inclination the seasons follow one another in regular cyclic order. The sun's radiation varies too, though the amount of variation is small. More minute factors, such as the different thermal properties of rock, sand, and soil areas, barren land and vegetation, forests, lakes, and rivers, all have their effects.

> Thus there is the spectacle of the atmosphere forever straining to follow its ordained equator-to-poles-and-return circuit, with the physical peculiarities of earth and sun conspiring to throw it off its track. The derailments are progressive; each one sets up new conflicts causing the air to back and shift, writhe and spin, billow and swoop—always seeking, never finding, equilibrium. In its wanderings it picks up the heat of the desert or the frigid chill of the glacier, and streaks off with it to far-off places. It collides with itself in tight corners and struggles for escape. It soaks up huge quantities of water and scatters it, sometimes frozen, back to earth. . . . All these aberrations of the atmosphere, in its search for rest, make the weather.[1]

Obviously, then, the list of factors that enter into weather conditions in one way or another is almost hopelessly long, and the factors interact in a most complicated and intricate manner. To analyze them so as to be able to predict the weather a day or two in advance appears next to impossible. Yet, owing to the progress of science, meteorologists are able to do this with a high degree of accuracy and dependability, as we shall see later.

The Air Contains Water Vapor. The most important component of the atmosphere in relation to its effect upon the weather is the water vapor it contains. The condition of the atmosphere with reference to its moisture content is known as its humidity. Relative humidity is expressed in terms of per cent, which means the percentage vapor content of the air at that particular time as based on the amount of moisture the air would contain if saturated under the given conditions. For example, a relative humidity of

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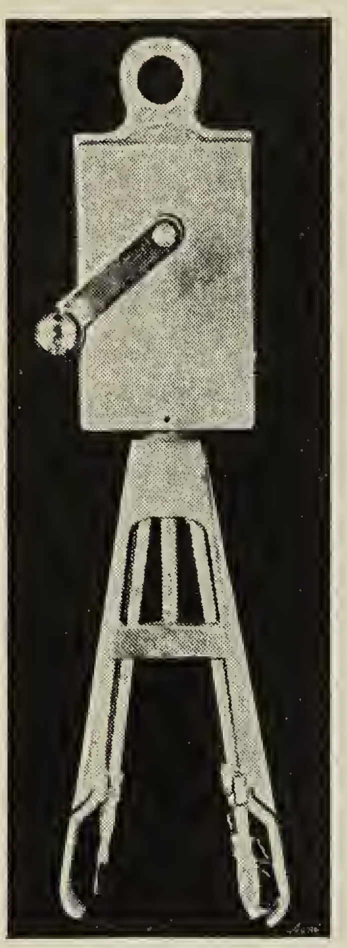
[1] *Fortune*, Vol. 21, pp. 137–138. (1940)

40 per cent means that the air at that particular time has but 40 per cent of the vapor which it would contain if saturated at the same temperature.



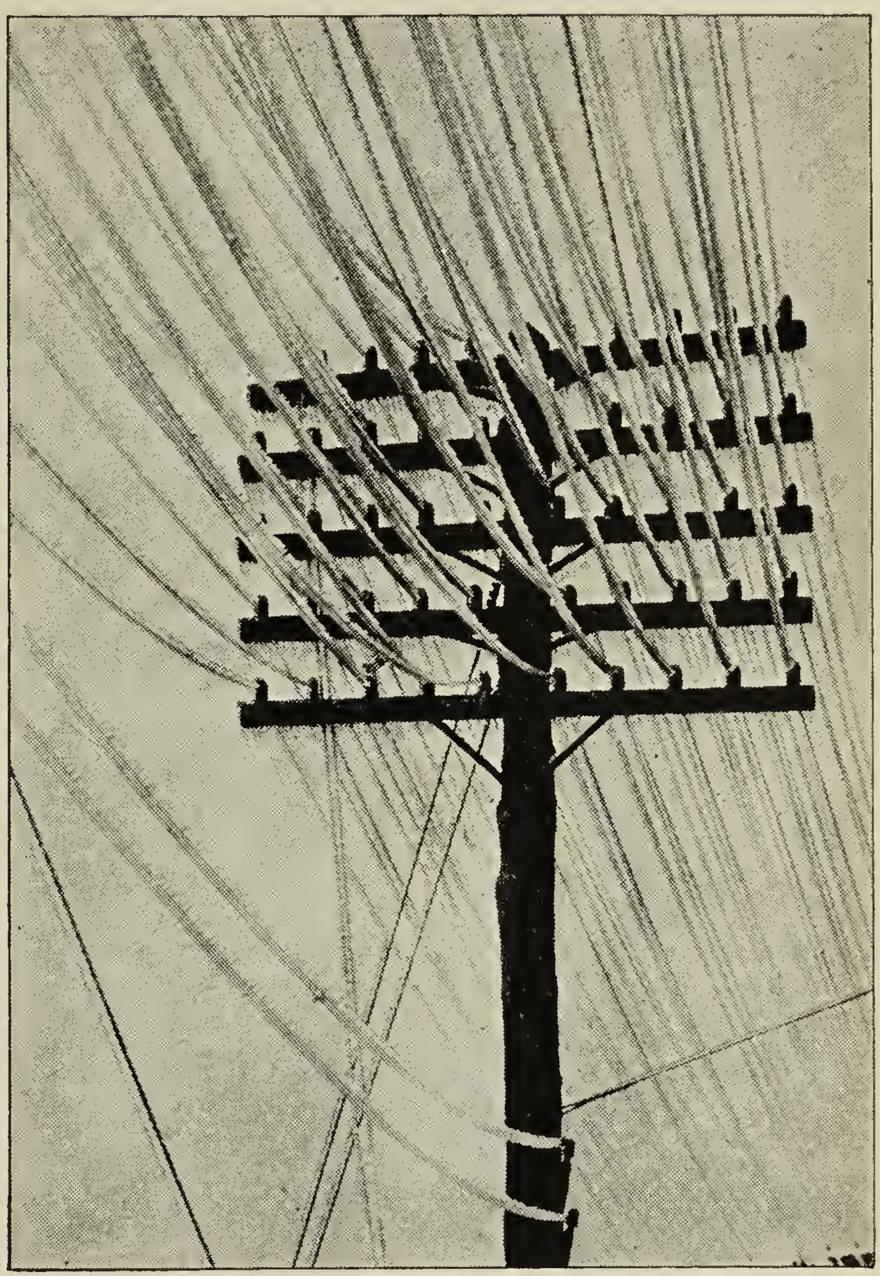
The psychrometer, an instrument for measuring relative humidity

It is estimated that on an average about 16,000,000 tons of water are removed from the earth's surface every second by evaporation. This comes from the soil, from leaves of vegetation, from rivers, from lakes, and from seas. The total annual evaporation from the surface of the oceans alone amounts to about 2.7 feet. If one could see molecules of vapor departing from a water surface on a warm day, these particles would constitute an upward-moving swarm all the time. He would also see some of them diffusing back into the water again. These particles which fly away through the air become the source of moisture supply for dew, fogs, clouds, rain, snow, and hail. At sea level there are on an average about twelve parts of water to every thousand parts of air. The water content diminishes rapidly with elevation. In the layer of atmosphere concerned mostly with our weather there are on an average probably not more than about five parts of moisture per thousand parts of air, although estimates as to this vary widely.

Dew, Fog, Clouds, Rain, Snow, and Hail Are Formed by Changes in Atmospheric Conditions. Dew does not "fall," as many people suppose. Heat dissipates away from objects at the surface of the earth, and the objects themselves become cooled and in turn cool the layer of adjacent air to the point of saturation. In this condition the air loses some of its moisture, which condenses and appears as dew on the surface of the cooled objects. The "sweat" deposited on the outside of a pitcher of ice water in warm weather is dew in the true sense of the word and is formed in exactly the same manner as nocturnal dews are produced.

One must not suppose that all the liquid moisture often found on the foliage of field crops and grassy meadows on summer mornings is real dew. Much of it is dew, to be sure; but some of the water clinging to these dripping leaves oozes out of the leaves themselves because of an internal pressure which under favorable conditions develops within the tissues. This exuded water is known as the *water of guttation* and is excessive when the days are warm and the nights are cool and humid and there is an abundant supply of moisture in the soil.

If the temperature is sufficiently low, moisture condensed from the atmosphere is not deposited as dew and then frozen afterwards. On the contrary, it congeals into fine, feathery ice crystals at the moment it condenses, and appears as frost. It is precisely in the same manner that a heavy coating of frost forms on the refrigeration pipes of artificial cooling systems.



American Telephone and Telegraph Company

Ice on telephone wires

Fogs and clouds are the same, in that they are formed of droplets of water or particles of ice which have condensed or congealed from the water vapor in the atmosphere. The only difference is one of position. When clouds form down next to the earth, we call them fogs; if they are above the ground, they are designated as clouds. This may be fully appreciated in mountainous regions. One on lower elevations may see a well-formed cloud come drifting down a cañon. Presently it arrives where the observer is. It now envelops him as a dense fog, and he unconsciously ceases to think of it as being a cloud. Aviators flying through the air speak of the handicap of fogs. In reality their trouble is one of clouds which they have encountered.

Condensation leading to fogs and clouds takes place when warm vapor-laden air expands by reason of reduced pressure and cools. This usually occurs when warm moist air is carried upward by convection currents into the higher atmosphere. Oftentimes by watching a not too distant cloud, one may see it forming at the top, where the air is rising and expanding. Off to the sides and usually lower down, portions of the cloud may be seen to vanish as the air in which they are formed descends below the saturation level. Sometimes the water drops formed in the cloud may be so large and heavy as to begin a more or less rapid descent toward the earth as raindrops. These too may disappear by evaporation again as they fall into the warmer or less humid layers of the atmosphere beneath. One can often spend a very interesting and instructive half-hour just sitting and watching the changes that take place in clouds as they move about in the sky. The weather bureaus, by bringing their observation instruments into play in this way, learn much about localized air currents.

Condensation of water vapor into liquid drops whether large or small always takes place about some nucleus as a starting point. These nuclei are salt particles, dust grains, or other minute particles of atmospheric matter. At first the water droplets are very minute. It is stated that a block of fog 3 feet wide, 6 feet high, and 100 feet long may contain less than one seventh of a glass of water, and that this is distributed in the form of 60,000,000,000 droplets. Under certain conditions cloud particles may coalesce into raindrops which are much larger (often ranging from one tenth to one fifth of an inch in diameter) and which, under normal conditions, fall with a rapidity commensurate with their size.

Snow, like frost, is congealed directly into ice crystals from water vapor while in the air. The crystallized designs are varied, depending upon the conditions under which they form. There are perhaps no more beautiful objects in nature than the delicate, feathery, and intricate designs of snowflakes.

During a severe thunderstorm, no matter how warm the weather, lumps of ice often fall, varying from the size of a pea or smaller up to, in rare cases, the size of a baseball or even larger. This is called hail. It occurs only in thunderstorms, though the electricity has nothing to do with producing it. It is caused by the swift uprush of air (like a draft up a chimney, only much stronger) which occurs in the thunderstorm cloud. This draft carries drops of water up to elevations so high and cold that they are frozen. As they fall back (which, of course, they must do) into the rainy portion of the cloud, they take on a new coating of water. At this stage they may again be caught in another strong updraft and be carried back to the freezing levels. This back-and-forth journey may take place several times until the roundish lumps of ice, thus formed of several shells, finally fall to the ground of their own weight as hail. To say that an object as heavy and compact as a hailstone is tossed up and down by air currents strikes one at first as almost preposterous; yet vertical air currents do possess unusual force. Captain I. E. Elm of the United States Air Service, retired, says:

> In riding in an airplane, flying through a rapidly rising current into a descending one, one will feel a bump similar to that experienced in riding an automobile over a rough road. The only difference is that you may have fallen or dropped several

hundred feet when you hit the bump. The next bump will be into an ascending current and it will carry the airplane up just as violently.[1]

Water reaching the earth from the atmosphere in all these forms is often spoken of as precipitation. The annual precipitation in the United States varies from about 1.45 inches in Death Valley, California, to over 100 inches along the upper Pacific coast. Perhaps the heaviest is in Tillamook County, Oregon, which has at one place an annual precipitation of 131 inches. The driest known spot on the globe is Arica, Chile, where the annual average for a period of seventeen years is 0.02 inch. The rainiest meteorological station in the world is at Cherrapunji, India, which records a yearly rainfall of 428 inches. The average annual rainfall over the whole earth has been estimated at about 32 inches.

Whirlwinds and Tornadoes Are Ascending Currents of Air Moving in a Spiral Manner. Everyone has seen miniature whirlwinds during still, warm afternoons of summer or autumn. Suddenly they form, twist along with great intensity for a variable distance, and finally dissipate as mysteriously as they began. If the spectator happens to be in its path, he very likely has the task of rescuing his hat a hundred yards or more away. The writer recalls having been a member of a picnic party in the Rocky Mountains one June day. At noon the table for the picnic lunch was spread when a whirlwind was noticed about fifty yards away coming up a relatively wide, flat-bottomed cañon. When it was within a few yards it unexpectedly shifted its course and passed directly over the table. There was a wild, rather unsuccessful scramble to cover the food and save it from the dust. The occurrence, however, afforded one of the best opportunities to observe the character of a whirlwind ever experienced. A bunch of paper napkins was caught up by the wind, and their movements as they scattered indicated the course of the aerial vortex. Some of the napkins were carried up, far above the summit of a mountain close by and, after escaping from the draft of air, presented a spectacle as they drifted about against the deep blue of the clear sky.

Such whirlwinds are caused as follows: Normally the air nearest the earth is heaviest and densest. Nevertheless, on warm, sunny days of late spring, summer, and autumn, the lower air, by contact with the warm earth, sometimes becomes heated and expanded until it is lighter than the layer of air above it. Since it is heated on all sides for some distance, there is insufficient lateral pressure to force the expanded air upward to maintain the atmospheric equilibrium. Then a condition of the air arises which has been likened to a layer of oil under one of water, or a cork held to the bottom of a vessel of water by pressure applied from above. Suddenly a hole, or passageway, develops in the overhanging ceiling of heavier air, and the warm air is pushed up through it, much as gases and smoke are through a chimney. The incoming air, like water flowing through the vent of a lavatory, sooner or later becomes directed to one side of the center, which sets up a whirling motion. The air's ascent in the vortex is usually slow. It required several minutes for the napkins, in the incident related above, to rise to the height of the mountain.

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[1] I. E. Elm, *Weather and Why*, p. 24. By permission, David McKay Company, publishers.

A tornado

Dust whirls may move very slowly. Humphreys tells us that Pictet observed one near Cairo, Egypt, which remained stationary for almost two hours over a small sand mound where it began. Later it slowly wandered away and was not lost in the distance until more than three hours later. Whirlwinds usually move along at a moderate rate and disappear as soon as they strike a situation, such as a body of water or green vegetation, where the conditions necessary to initiate and maintain them do not exist.

Tornadoes are whirlwinds of a different kind and must not be confused with these small dust whirls. The two are wholly different in both origin and character. The cause of dust whirls exists down near the surface, whereas that of tornadoes resides in the region of the clouds. Dust whirlwinds are of little consequence, but tornadoes may be extremely violent and destructive. The latter are sometimes called "cyclones," but this word is confusing and is erroneously used in this connection. By the residents of the American prairies, where they are most likely to occur, tornadoes are often dubbed "twisters," which is certainly a vividly descriptive term.

A tornado is defined by Humphreys as being "a slightly funnel-shaped, hollow, circular column of upward spiraling winds of destructive velocity."[1] These storms are localized in extent, but are certainly the most violent within their limits of all the atmospheric disturbances known to man.

They usually occur in the spring or early summer and travel along from twenty-five to forty miles an hour and over a path ordinarily from twenty to forty miles in length, although it may be either shorter or longer in extent. Though they vary in width, they average about one thousand feet. Tornadoes are much more likely to occur in the late afternoon or early evening.

The causes of tornadoes are imperfectly comprehended, and the action of the forces believed to be involved is entirely too complicated for the layman to understand. Suffice it to say that they are always accompanied by a spinning, funnel-shaped cloud with its small end pointed toward the earth. The color of the cloud is a greenish gray to yellowish black, and its lower extremity often twists about in serpentine fashion. As the great funnel moves along, it is accompanied by a deep roar, often punctuated by sharp, crashing, staccato noises, which makes its whole aspect terrifying in the extreme.

The center of the vortex is a partial vacuum (possibly a 10 per cent vacuum, not more) enclosed by a gyrating wall of air with a rotatory velocity reckoned at from one hundred to two hundred miles per hour. In some places the speed may be as high as from three hundred to five hundred miles per hour. These, it must be remembered, are estimates only, for the conditions within a tornado have never been measured directly.

The destructiveness of tornadoes is due in part to the partial vacuum within the funnel. Buildings destroyed within their path often have the walls forced outward as if by an internal explosion. This arises from the outward push of the air within the walls when the outside pressure is very suddenly reduced by the structure's being engulfed within the moving vortex. Peculiar freaks are often performed by these storms. On one occasion the roof and walls of a school building were torn away, leaving the teacher and the children, with but minor injuries, remaining on the floor. Sometimes pieces of lumber may be driven through the trunks of small trees. If a tornado goes out to sea, it forms a waterspout, which may be very spectacular.

Tornadoes in the United States occur mostly in the central and southeastern states. They form also in Australia and other parts of the world outside the tropics.

[1] W. J. Humphreys, *Physics of the Air* (Third Edition), pp. 151–155 (1940). McGraw-Hill Book Company, Inc., publishers.

Highs and Lows Are Important in Forecasting Weather. In addition to the general atmospheric circulation already noted, there occur in both the Northern and the Southern Hemisphere great whirlpools of air much like eddies moving downstream in a river. In a sense they may be considered to be migrating atmospheric disturbances superimposed upon the more general circulation. On the whole, these great cyclone and anticyclone areas, as they are called, are more characteristic of the Temperate Zone belts, and move eastward owing to the impelling effect of the prevailing westerlies. Their existence is made evident through the daily weather reports, which, along with other readings, give the barometric pressure and the direction of the wind at the different stations. Prediction as to the kind of weather to expect is based upon the general direction of movement, size, pressure gradients, and other characteristics of these air movements.

Essentially a cyclone, or low, is a great circulation of air about a center of low pressure, and an anticyclone, or high, is such a movement of air around a center of high pressure. There are two or three theories as to how cyclones and anticyclones originate. The most acceptable to meteorologists, however, is the *polar-front theory*, proposed by the Norwegian meteorologist Vilhelm Bjerknes. By this theory highs and lows become secondary phenomena, symptomatic of still more remote weather causes.

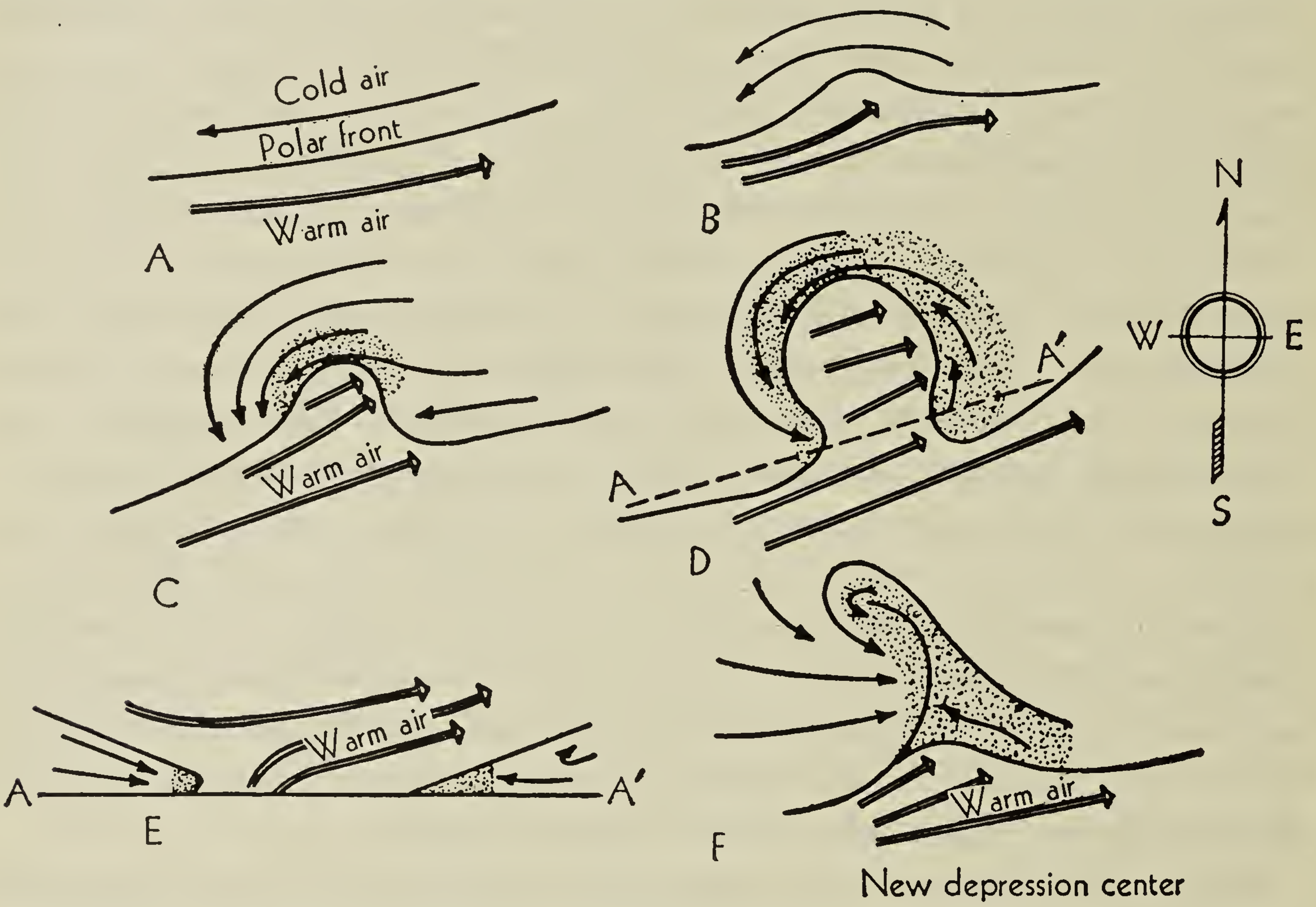
Bjerknes and his son Jacques, who is associated with him, envisage great masses of air which stagnate over some geographic area called a source region. Masses of this sort take on the temperature and moisture conditions characteristic of the region over which they form. For instance, air masses which develop in the polar regions are cold, and those which form in tropical regions are relatively warm; those which form over land are dry, and those which arise over water are correspondingly wet. Moreover, these characteristics are not limited to just the air near the surface but apply also to the air extending several miles aloft. In this way extensive masses of relatively quiet air develop. To be more specific, the warm waters of the Gulf of Mexico and the Caribbean Sea and similar areas in the Pacific Ocean between Hawaii and Lower California are regions over which great masses of warm, moist air accumulate. On the other hand, the cold snow-covered and ice-covered regions of northern North America and the adjacent Arctic Ocean favor the development of most of the immense cold, dry air masses which affect the United States and Canada. The northern part of Alaska, where air movement averages from 30 to 40 per cent less than in the United States, is a region particularly favorable to the development of cold air masses. *It is these air masses which the Bjerkneses conceived to be the causative factors in weather changes.*

At length, owing to unbalanced conditions, chiefly of temperature, in the atmosphere these air masses begin to move, the cold ones tending to drift southward and the warm ones northward. They are pictured as being 30,000 feet thick sometimes, and once under way they may twist and curl and thrust out great tongues in their progress over the surface of the earth. But such masses of air, several miles deep and hundreds of miles across, may travel long distances and still retain, in the main, the characteristics of the region from which they originally came. Only slowly and gradually are these characteristics modified by the new atmospheric conditions which are encountered.

In their migratory progress, when a cold, dry air mass from the north meets a warm, moist air mass moving in from the tropics, they do not immediately mix. On the contrary, the surface of contact between the two becomes a rather well-defined temperature boundary. This boundary is not a thin, sharply marked plane but is rather a mixing zone, possibly four or five miles thick. This zone is known technically as a *surface of discontinuity* or an *air front.* It is along such an air contact, with the contrasted differences in temperature and humidity between the two masses, that principal weather changes and disturbances occur. It may result in variable winds, clouds, rain, hail, snow, or other turbulent weather phenomena, the form and intensity of which depend on the contrasted characteristics of the two dissimilar air masses and the rapidity with which they are brought together.

Both cold fronts and warm fronts are recognized. *Cold*, as used in this connection, means that the more rapidly advancing air mass, whatever its temperature, is colder than the surface *over* which it flows. *Warm* means the opposite; and this distinction should always be kept in mind. A *cold front*, the commonest region of pronounced weather changes, occurs when an advancing cold, and consequently denser, air mass wedges itself under a warm and less dense mass which it encounters. In this way the warm air is forced to ride up over the cold mass, where it cools by expansion and drops its moisture. The front corresponds to the trough of the low. On the other hand, when the warm air mass is moving in rapidly and overtakes a retreating cold mass, the contact surface between the two becomes a *warm front.* Here too the warm air, because of lower density, glides up over the heavier cold air and is elevated. So along both fronts warm air rises, expands, and tends to drop its moisture. The weather disturbances along a cold front, however, are likely to be more pronounced because the upward thrust of the cold air as it advances elevates the warm air more rapidly and thus accelerates expansion, with its consequent cooling and precipitation. These air-mass encounters, it must be reiterated, are the chief centers of weather disturbance. Whenever the contrast in characteristics is sharp enough, shifting winds, changing barometric pressure, and precipitation of some kind always follow.

In addition to this "frontal" weather, atmospheric changes sometimes occur within the air mass which may result in meteorological disturbances. These internal conditions may arise from the characteristics of the air mass itself and the topographical features, such as water surfaces, deserts, mountains, forests, and the like, over which it may pass.



A diagram to illustrate the development of a polar front according to the Bjerknes hypothesis

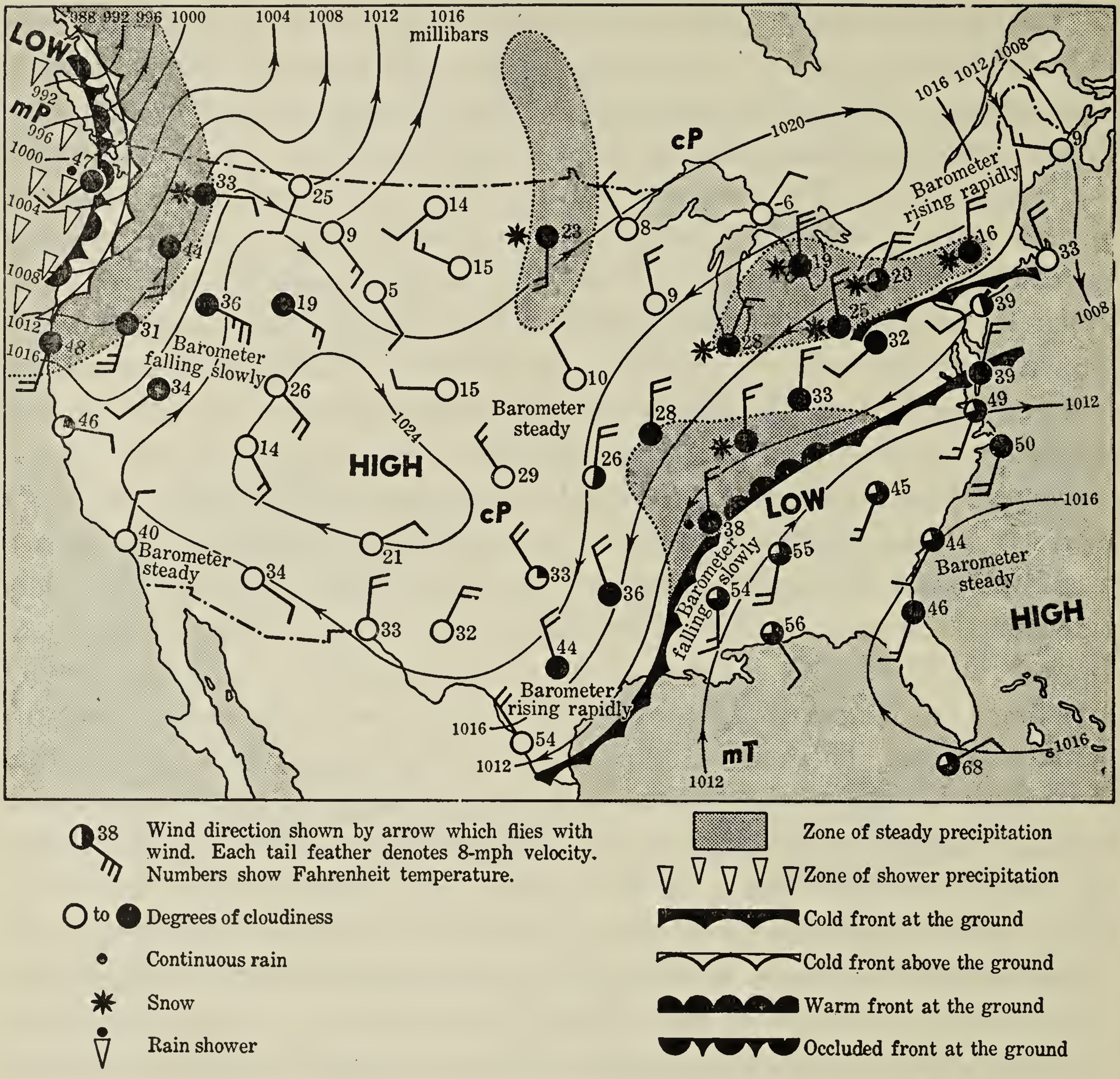
It must be emphasized that air-mass and air-front analysis apply mainly to the Temperate Zone regions of the earth. In the tropics practically all the atmosphere lying near the earth's surface is warmed together, and in the polar regions it becomes rather uniformly cold. It is chiefly, then, in the Temperate Zone regions that these contrasted air masses come together and that marked, turbulent weather changes are likely to occur.

The extent of these air masses almost staggers the imagination. Numerous estimates place the masses of air moved in the order of from 10 billion to 100 billion tons, and this represents only a small part of the total air mass overlying the surface area concerned. Shaw appropriately states that "the creation of a cyclonic depression is an undertaking which altogether transcends the capacity of human agencies."

The study of such enormous atmospheric masses as these can be attacked only by commensurately extensive vertical as well as horizontal atmospheric observations. It is for this reason largely that the airplane, pilot balloon, and, more recently, the radiosonde have been called into use.

Irregularities of flow along air fronts, particularly the cold or polar fronts, are believed to produce huge tonguelike projections of the warm air mass into the cold air mass, and thus areas of low barometric pressure are believed to be initiated. Consequently it is along these fronts that the cyclonic air-whirls known as lows, extensively utilized by the Weather Bureau in their work, are believed to originate. As has already been stated, air-mass analysis indicates that these lows and their generally succeeding highs are but symptoms of air-mass conditions which produce weather changes, not the fundamental causes themselves. Nevertheless it would be very difficult to portray graphically air-mass conditions that presage weather disturbances, even if they could be fully determined. Instead of the old familiar weather map, with its "highs" and "lows," the Weather Bureau has just recently begun the issuance of a weather map based on air-mass analysis. This map is simple and more graphic than the old familiar one. The most striking change in the new map is the substitution of symbols indicating the position and movement of air masses for the old familiar concentric ellipses of isobars and isotherms. Some of the symbols are almost self-explanatory. Thus a white circle means a clear sky, and a black circle a completely cloudy one; intermediate amounts of blacking-in tell of skies clouded from one tenth or less to nine tenths or more. A zigzag line with an arrow at the lower end means a thunderstorm. A small round black dot means rain, and different numbers of this dot placed in different positions indicate rainfall from a slight shower to heavy, continuous rain. Altogether there are 148 symbols. At present the new map is being issued only from Washington, D.C., but it is planned to extend this service to other points as printing facilities become available. Eventually this map will become the standard weather map for the entire country, but the complete change-over will doubtless take several years.

Reverting to the old form of weather map, in general use now, the highs and lows, which are symptomatic of polar fronts, tend to move across the United States in fairly regular succession, one following the other. The time elapsing between the departure of one and the arrival of the other varies considerably, but the interval usually ranges from three to seven days. The speed at which they travel varies, too. Some move much more rapidly than others. Perhaps the average rate of progress might be put at twenty-five miles an hour, or six hundred miles a day. Their rate of progress may fall as

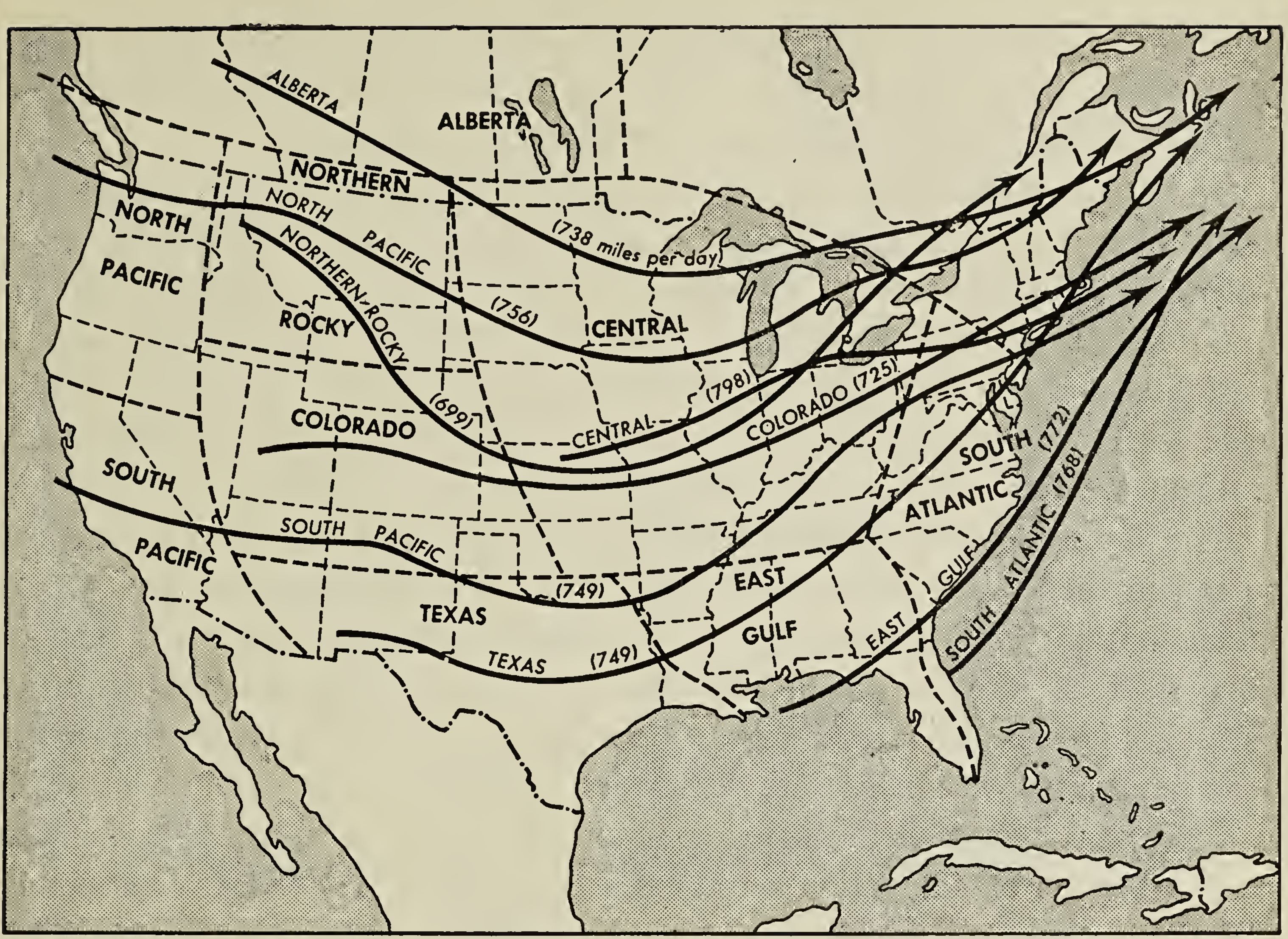

988 992 996 1000 1004 1008 1012 1016 millibars
LOW
mP
cP
1020
HIGH
1024
cP
Barometer falling slowly
Barometer steady
Barometer steady
Barometer rising rapidly
Barometer rising rapidly
LOW
Barometer falling slowly
Barometer steady
HIGH
mT
1012
1016
1008
38 Wind direction shown by arrow which flies with wind. Each tail feather denotes 8-mph velocity. Numbers show Fahrenheit temperature.
to Degrees of cloudiness
Continuous rain
Snow
Rain shower
Zone of steady precipitation
Zone of shower precipitation
Cold front at the ground
Cold front above the ground
Warm front at the ground
Occluded front at the ground

A weather map constructed on data derived from a study of air-mass analysis (based on map in April, 1940, Fortune)

low as three hundred miles a day, however, or it may be accelerated to a thousand miles, depending altogether upon conditions.

If the characteristics of the highs and lows are pronounced and if they move with considerable speed, abrupt changes may be expected; if, on the other hand, their characters are poorly defined and they move slowly, fairly equable weather may be predicted. If people in general possessed this knowledge as to the main symptoms of weather and would then seek the free information furnished by the Weather Bureau to guide them in their pursuits, doubtless property losses to the extent of millions of dollars annually could be avoided.

In general, there are two more or less well-marked storm routes across the United States. These lows and highs originate mainly either over the Pacific


ALBERTA
ALBERTA
NORTHERN
NORTH PACIFIC
NORTH PACIFIC
NORTHERN-ROCKY
ROCKY
(738 miles per day)
(756)
CENTRAL
(798)
CENTRAL
(699)
COLORADO
COLORADO (725)
SOUTH (772)
SOUTH ATLANTIC (768)
SOUTH ATLANTIC
SOUTH PACIFIC
SOUTH PACIFIC
(749)
TEXAS
TEXAS
(749)
EAST GULF
EAST GULF

The North and South Pacific general storm paths

or over the southwest area and move eastward. Those from the Pacific come in from the northwest. They usually bend southward in their course and later curve back across the Great Lakes states and pass down the St. Lawrence valley to the sea. The lows coming from the southwest tend to traverse the central Rocky Mountain region, and then, taking a northeasterly course, their path converges with the course of those from the Pacific. Sometimes the lows and highs bend south over the Gulf states in their progress and then later tend to curve back sharply toward the region of the Gulf of St. Lawrence. Departures of the highs and lows to some degree from these general paths are not infrequent.

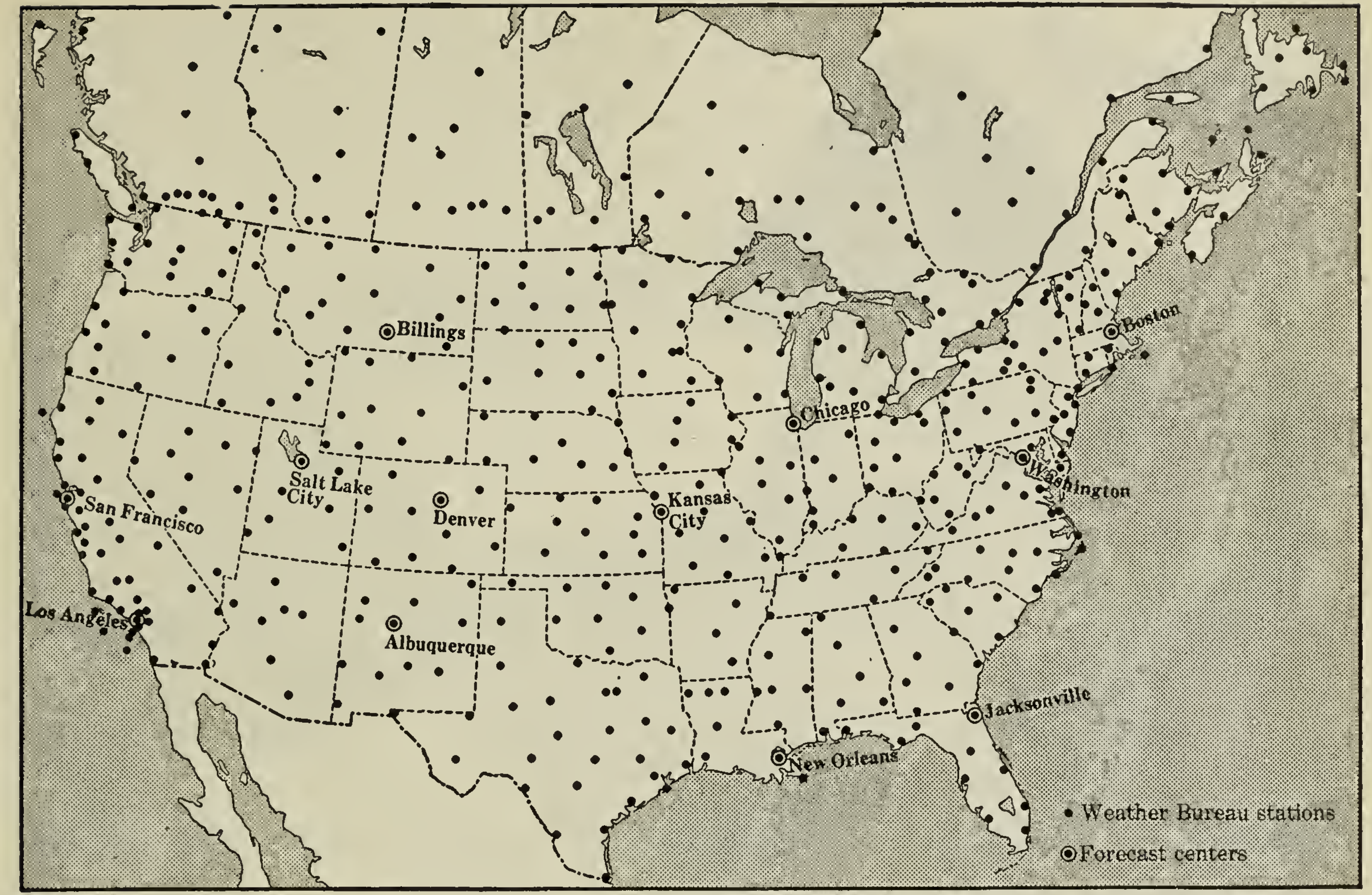
Moreover, the migratory cyclones of the Northern Hemisphere are not only likely to follow certain routes across the United States but are also inclined to follow a more or less well-defined course around the earth. In Asia the path becomes rather diffuse, but they have been known to traverse that continent as well. The distance they travel depends, of course, largely upon their size and intensity. Some may be traced for long distances; others are feeble and many become dissipated and vanish altogether. According to C. L. Mitchell of the United States Weather Bureau the first recorded storm to circle the globe was a low that originated in Montana on February 23, 1925. It traveled 21,379 miles and, after starting on its second round, became dissipated in the Gulf of St. Lawrence on March 23 following.

The cyclones occurring within the tropics (tropical cyclones) are smaller on an average than those of higher latitudes and in many cases are the most violent of all storms except tornadoes. Those occurring in higher latitudes (extratropical cyclones), whether originating there or in the tropics, usually bring about marked changes of weather and temperature during their passage; their winds may be high or otherwise. Tropical cyclones are also called hurricanes (when violent), typhoons, or baguios.

The United States Weather Bureau. The early advocates of a weather bureau in the United States had a hard time to win support for their cause and to obtain funds to begin the work. After a long agitation to persuade Congress that forecasts of the weather were practicable, and after storm-warning and weather-forecasting services had been established in Europe, a corresponding government service was established in this country in 1870 as a part of the work of the signal corps of the army. At first the service was for the benefit of navigation on the seacoast and on the Great Lakes, but soon other duties were added. For twenty years the work was carried on by the War Department. By that time its services had earned such a recognition in the business and civil life of the nation that on July 1, 1891, the Weather Bureau of the United States Department of Agriculture was established. Its work has grown and expanded, both in personnel and services rendered, until today it is recognized as one of the most efficient and important bureaus of the Federal government.

The bureau now compiles daily records of temperature, precipitation, and other meteorological data at some 5500 points in the United States and its possessions. The greater number of these observations are made and recorded by amateur weather-observers some of whom have been in service forty or fifty years continuously without a cent of pay. As one of the latest developments there are now in operation in the United States and its possessions some fifty radiosonde stations taking observations twice a day. The flights made at these stations usually extend to heights exceeding ten miles. Altogether the bureau has about 2100 regular employees, and for its support an annual outlay of a little over $6,000,000 is needed. Doubtless during the present war the services have cost far more than that figure.

To facilitate the work the United States proper is organized into fourteen forecasting centers, including those in Alaska, the Hawaiian Islands, and Puerto Rico. Each has its quota of other surrounding and co-operating

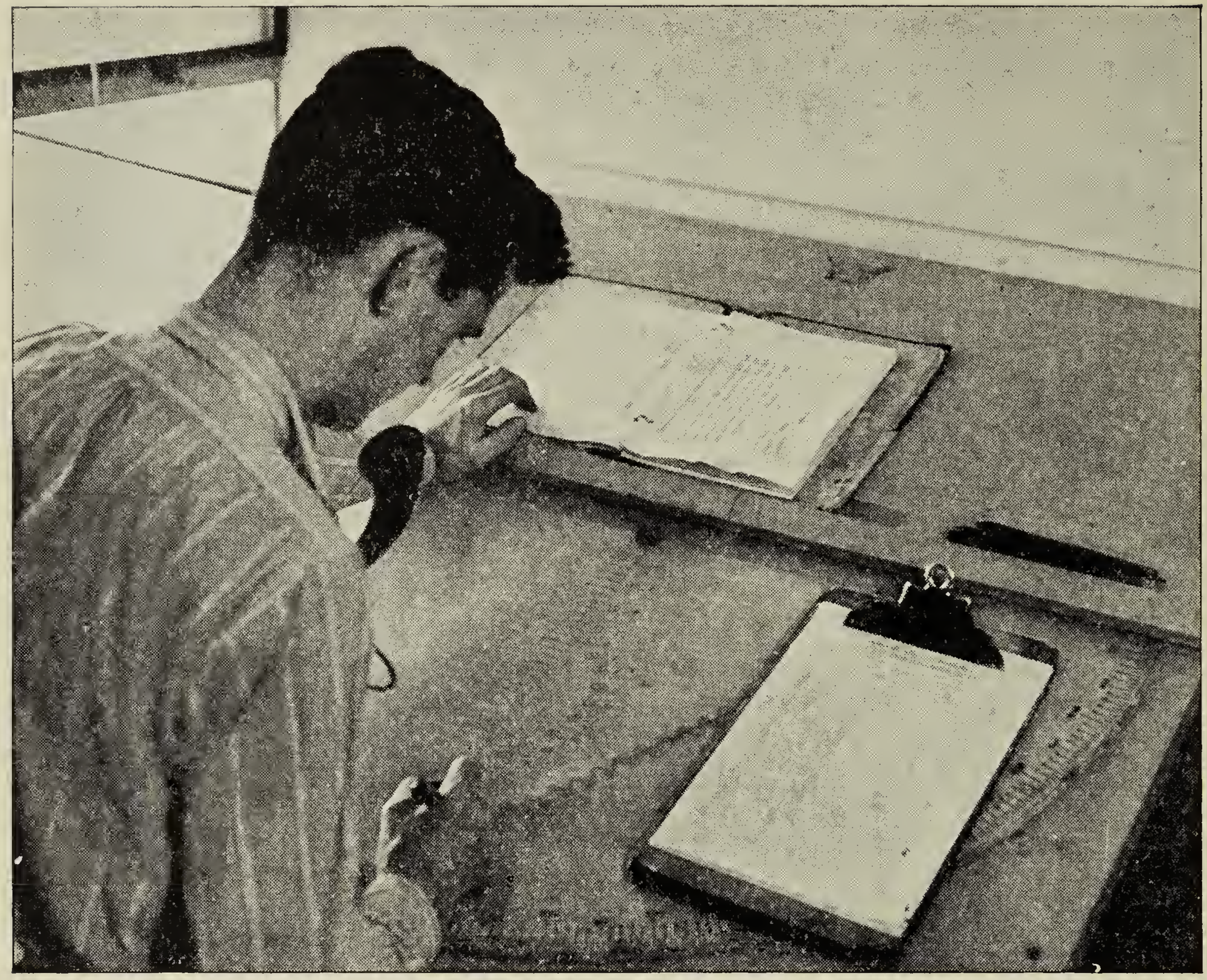

Billings
Salt Lake City
Denver
San Francisco
Los Angeles
Albuquerque
Kansas City
Chicago
Washington
Boston
Jacksonville
New Orleans
• Weather Bureau stations
◉ Forecast centers

Distribution of Weather Bureau stations and forecast centers

substations. These taken together constitute the skeleton of the *general weather service* and are the sources from which come the general weather reports read in the newspapers or heard over the radio.

At 1.30 A.M. and 1.30 P.M. and likewise at 7.30 A.M. and 7.30 P.M. (Eastern Standard Time) some eight or nine hundred observers well distributed over the United States and adjacent territories read their instruments, observe the sky, and within twenty minutes send a wire, in numerical code for the sake of brevity, to their designated district offices. From these detailed data general weather-service reports for each district are rapidly compiled. On the basis of these results forecasts are made for the different regions for the next thirty-six to forty-eight hours. Reports from the district stations are sent to the central station at Washington and are compiled for the whole country.

Within two hours after the morning observations have been taken, reports are going back from the different forecasting stations to nearly two thousand principal distributing points, whence they are farther disseminated by telegraph, teletype, telemeter, radio, and mail to merchants, manufacturers, shippers, and farmers, apprising them of the kind of weather their activities are likely to encounter. By a system of interchange, daily reports also are received from a number of stations in Canada, Mexico, and Central America.



United States Weather Bureau

Receiving weather reports at a forecasting station

Red-and-black storm-signal flags are flown from the roof of the local weather bureau at shipping points along the Atlantic, Pacific, and Gulf coasts, and shores of the Great Lakes, including every port and harbor of any considerable importance. So nearly perfect has this service become that for years few storms of marked danger to maritime interests have occurred for which ample warnings have not been issued from twelve to twenty-four hours in advance. The sailings of the immense number of vessels engaged in our ocean and lake traffic are determined largely by these warnings, and those displayed for a single hurricane are known to have detained in port on our Atlantic coast vessels valued with their cargoes at over $30,000,000.

The warnings of frosts and freezing weather are also of immense value, particularly to the fruit, sugar, tobacco, cranberry, and market-gardening interests. The early-truck-raising industry, extensively carried on in the regions bordering on the Gulf and South Atlantic coasts and in Florida, is largely dependent for its success on the co-operation of the Weather Bureau. In the citrus and deciduous fruit districts too these warnings are of inestimable value.

Acting on the advice of fruit-frost specialists that an unusually severe frost would perhaps be experienced in a day or so which would probably require an additional fuel supply, the growers in southern California on Christmas Eve and Christmas Day, 1924, to meet the impending emergency, rushed into the orange groves three hundred carloads and one hundred and seventy-five truckloads of oil to be used in the orchard heaters. During one cold wave in this district alone $14,000,000 is estimated to have been saved by the growers' taking advantage of these warnings.

Railway and transportation companies make continued use of the weather forecasts in many of their shipments to protect them against extremes of heat or cold as conditions may require. Often the shipments of perishable goods are accelerated to push them to their destination ahead of unfavorable weather conditions. If this is impracticable, the perishables may be run into roundhouses for protection. If warnings are issued in advance of acceptance, the carriers may refuse to start shipments of this character until after the danger is past.

In the raisin-growing districts of California rain forecasts are of great value. While the raisin crop is drying, it is extremely susceptible to injury from rain if the trays containing the fruit are not stacked and covered during inclement periods. The accuracy of the rain forecasts for this region and the system for their distribution have been so reliable that practically no loss from this cause has occurred for years. Rain forecasts are also utilized in the digging of vegetables and their preparation for the market, in the harvesting of broomcorn, and in the cutting and baling of alfalfa and other forage crops. Rain forecasts are also of much benefit in fruit districts in connection with spraying operations and in other districts during harvest.

The uses made of temperature forecasts in the cities are more varied than is generally supposed. With notice of an approaching cold wave greenhouses are closed and boilers are fired. Preparations are at once made by heating and lighting plants, whether gas, electric, steam, or hot-water, to meet the increased demands that will follow. Fireplugs, exposed water mains, and general plumbing are protected. Large stockyards drain their mains. Gasoline engines are drained, and water-cooling systems of automobiles are protected by use of antifreeze solutions. Work in concrete is stopped, and street-railway companies arrange for more heat in their cars. Natural-gas companies turn a larger amount of gas into their lines to provide for increased consumption. Merchants curtail advertisements or direct attention largely to cold-weather articles. Coaldealers plan to meet the heavier demands. The dredging of sand and gravel ceases, and iron ore piled up for shipment is placed in holds of vessels to prevent the wet masses from freezing solid.

Warnings of heavy snows are very valuable to railroads in that such warnings enable them to organize their snow-fighting equipment and to reduce, if necessary, the tonnage of their freight and passenger trains. Storm forecasts sent out by radio are also invaluable to the great ranches on the Western plains, where the stock is hurried from the ranges to shelter upon notice of an approaching norther or blizzard.

Weather Bureau forecasts are front-page news. Each morning every district office of the Weather Bureau is full of messengers waiting to snatch copies of the daily weather map and rush off with it to the offices of shippers, produce markets, brokers, and public-service corporations. The extent to which private citizens too depend upon this information is revealed by the fact that in New York City alone an average of 16,000 persons spend five cents a day to call the specially provided telephone number WEather 6-1212 for the latest prediction. Indeed, this number on peak days has received as many as 57,000 calls.

More recently weather reports and predictions have come to be indispensable to aerial transportation. The entrance of the airplane into the freight, express, mail, and passenger-carrying business has made heavy demands upon the Weather Bureau. There is perhaps no other enterprise that follows weather forecasts more closely and profitably than that of aviation. Calls for assistance from this source have been so pressing that the bureau has set up a special *airways service* for the express purpose of meeting the needs of those engaged in aeronautical pursuits and aerial transportation. This division has thirteen districts with some fifteen hundred paid and unpaid employees. In addition, off-airway co-operating stations between the airports carry about two hundred paid employees.

Observers in this service read their instruments and make observations regularly every hour throughout the whole night and day. One hundred thirty of these airport stations are authorized to send up pilot balloons at designated periods four times within each twenty-four hours. The army and navy meteorological stations, of which there are about seventy-five, also make pilot-balloon observations regularly at stated hours and at such other times as their needs require.

From the district stations weather reports for the benefit of airplane pilots are issued every six hours. In addition, some of the stations, as the one at Denver, send out a constant radio beam to guide airmen toward port. Moreover, local hourly weather reports are broadcast by voice for the convenience and safety of aviators in that locality.

During the summer of 1940 the coast-guard cutters *Bibb* and *Duane* were detailed as a sort of "weather patrol" to assist the Weather Bureau in studying meteorological conditions along the Atlantic-clipper airplane route. One was stationed one third the distance to Europe from the American shore and the other two thirds the distance across. Each ship went to its respective spot in the Atlantic and stayed there for three weeks, obtaining all possible weather data and relaying it back to the Weather Bureau, where it was made available for the use of the mail-carrying Atlantic clippers and for surface-shipping officials of all nationalities.

When these ships returned, their place was taken by two other ships, the *Hamilton* and *Ingham*, which served until the first ships could return to their posts of observation.

In the summer of 1940 the Weather Bureau began a test series of new long-range weather forecasts. These forecasts are made twice a week and cover a period of five days. They are issued from ten cities, designated as district headquarters by the Weather Bureau, and are based on such air-mass data as can be gathered, as well as information gained from the conventional sources. In making these forecasts the bureau is trying to get away from vague generalities and the great areas of coverage which characterized the old, weekly broadcasts and narrow their forecasts down to specific localities and fairly definite predictions. If these broadcasts can be made reasonably reliable, they will greatly enhance the value of the Weather Bureau's service to aviation, commerce, and the general public.

In concluding this chapter we wish to point out that Charles Dudley Warner's witticism to the effect that "everybody's talking about the weather, but nobody's doing much about it" is a long way from true today. It is a fact that man is powerless to control weather in any sense of the word, rain-makers and sign-venders notwithstanding. Nevertheless, by the increase of meteorological knowledge and the improved methods of dispatching information, man these days is doing much about the weather. He is planning his activities on the basis of weather forecasts to such an extent that doubtless many lives and millions of dollars' worth of property are saved every year. A careful comparison of the forecasts with the weather over a number of years shows a reliability of from 85 to 90 per cent. This is a high degree of reliability, but it is sure to be higher as meteorological science advances.

Questions for Study

1. How do the various positions of the earth in its orbit influence the living conditions of man?

2. In what ways have man's ideas regarding the causes of weather been changed through a scientific understanding of the atmosphere?

3. How would you distinguish between *weather* and *climate*?

4. What are believed to be the chief factors which are responsible for weather?

5. How is the relative humidity of the air related to the health and living conditions of man?

6. How are human activities, such as communication and transportation, affected by weather?

7. How do meteorologists explain the phenomena of tornadoes and waterspouts?

8. Upon what conditions are modern weather predictions based?

9. Why is the barometer reading one of the best indicators of the kind of weather to expect?

10. Why is it that weather conditions which are predicted sometimes do not occur?

11. What is one of the important factors that determine the region which people select as a place to live?

12. How does the fact that an airline pilot is required, when possible, to know the weather conditions in advance in order to plan his flight emphasize the importance of weather maps and reports?

13. What are some of the occupations of modern man that are dependent to a large degree upon the conditions of the weather?

14. In what ways do modern methods of predicting the weather differ from the methods used by our grandfathers?

15. How many atmospheric conditions can you name that contribute data upon which weather reports are based?

16. What principle of valid thinking is embodied in Socrates' reply to Strepsiades in this chapter?

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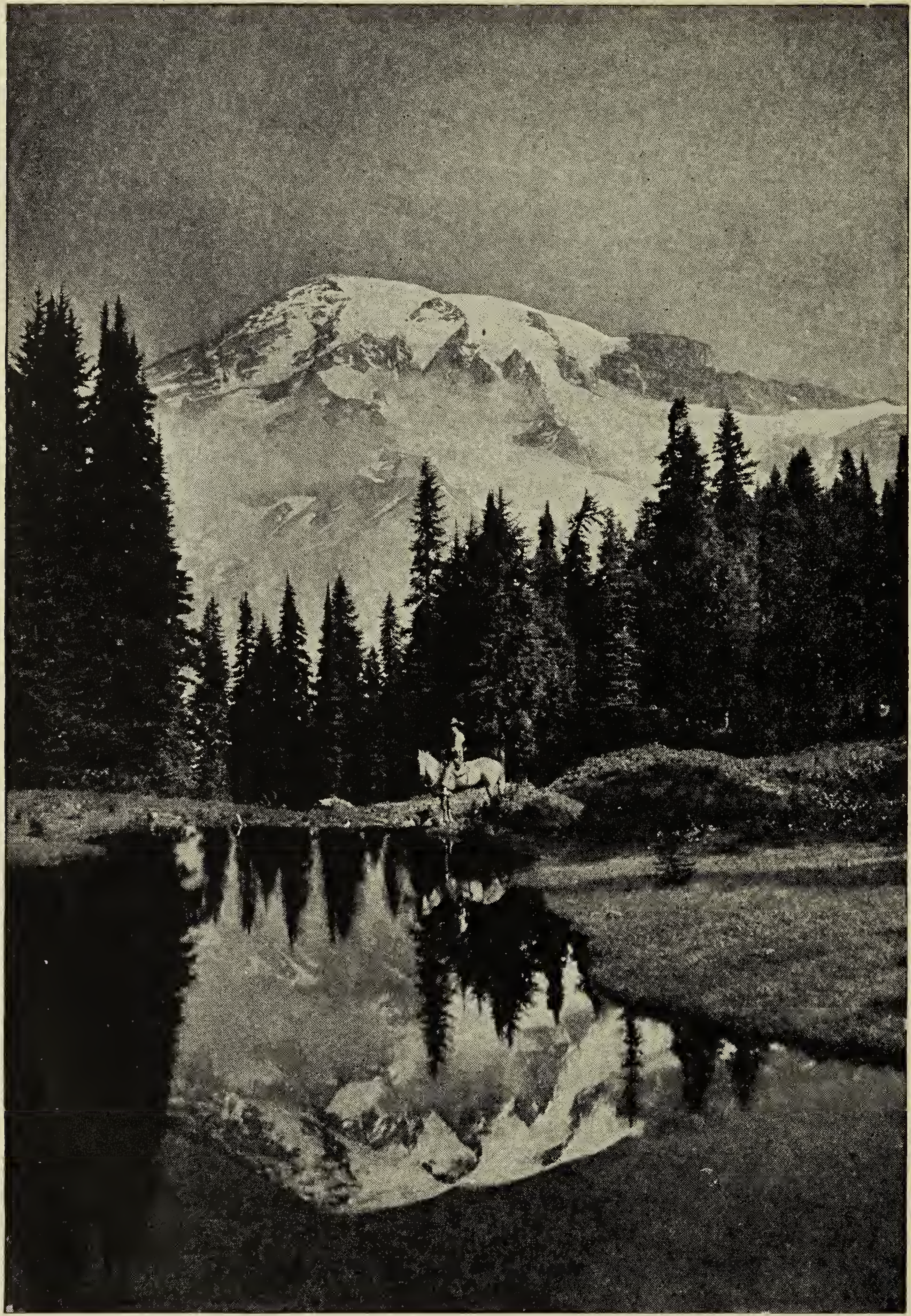
UNIT SIX

The Earth's Surface Is Continually Changing

Man knows little about the deep earth. His knowledge is confined largely to its surface features, and even about these he often holds erroneous ideas. Within the brief span of a man's lifetime the earth's surface seems permanent and unchanging. In the evening of one's life the hills and valleys appear to remain much as they were in the days of his youth. Plains stretch out just as they did in childhood, and the mountains give the same impression of steadfastness and immovability.

Yet earth history, slowly written by the forces of time on the face of rock, cliff, and cavern, denies the idea of permanence. These geological pages show rather that the earth is a changing place. Transformations of magnitude may take place slowly and require ages for their completion; but they occur nevertheless. Mountains and plateaus are worn down and dumped into the sea. The bed of the sea subsides, and mountains are elevated again either on the same site or a different one. Parts of the continents may sink and become portions of adjacent seas; the sea bottom may be pushed up and become dry land.

So the cycle has moved and will move. For this reason the study of the earth's changes and their relation to man is one of the most interesting, profitable, and fascinating of intellectual pursuits.



Union Pacific Railroad

Mt. Rainier, a peak of volcanic origin

CHAPTER TWENTY-SEVEN

The Radial Structure of the Earth Is Inferred from Indirect Evidence

Continents Are Elevated Portions of the Earth's Crust. A continent is "like a huge, curved buckler [or shield-shaped portion of the earth's crust] resting on the body of the earth" and more or less completely flanked by the deep ocean. For our purpose, from this point of view, we may say that there are five such continents: North America, South America, Australia, the large land area about the south pole called Antarctica, and the huge land mass of Asia, Europe, and Africa, which may be taken as one gigantic continent. The average height of the continental areas, if they could all be brought to a common level, would be somewhat less than one-half mile above the surface of the ocean.

Here and there arms of the sea extend into and overlap these buckled areas. Hudson Bay, Bering Sea, and the Gulf of Mexico furnish familiar examples. Along the margins of all the continents the land has gradually been worn off by the ceaseless pounding action of ocean waves, so that a comparatively shallow, submerged shelf has been formed. This shelf in many places has been added to by the gradual deposit of sediments planed off the face of the continents, mainly by water, and transported down to the sea. These *continental shelves*, as they are technically known, vary in width from 10 to 300 miles or more. They slope out gently to a line where the ocean soundings show a depth of from 300 to 700 feet. At this outer edge the descent is relatively abrupt to the general level of the sea floor, which is from 12,000 to 13,000 feet below the surface of the water. The dry land covers about 30 per cent of the globe; and when the continental shelves are added, it swells the buckler area to about 40 per cent of the total earth's surface.

Although the level of the continents has shifted up and down at different times in the earth's history for reasons not clearly understood, nevertheless in general the continental forms seem to have been rather permanently and steadily preserved.

The Visible Layers of the Continental Bucklers Consist Chiefly of a "Basement Complex" Regionally Veneered with Other Materials. As a result of careful study, earth scientists have learned much regarding the geological characteristics of the continental floors. This research has been carried on largely in the presence of artificially or naturally bared strata.

For our purpose, in the light of these findings, we may think of the continental areas as being composed of three elements. The chief one is that of a thick layer which, except where broken by fissures and lava flows from beneath, forms a continuous structure from shore to shore and even beyond toward the outer limits of the continental shelves. This layer has been called the "basement complex." Beneath the complex are other supporting layers, which we shall note later.

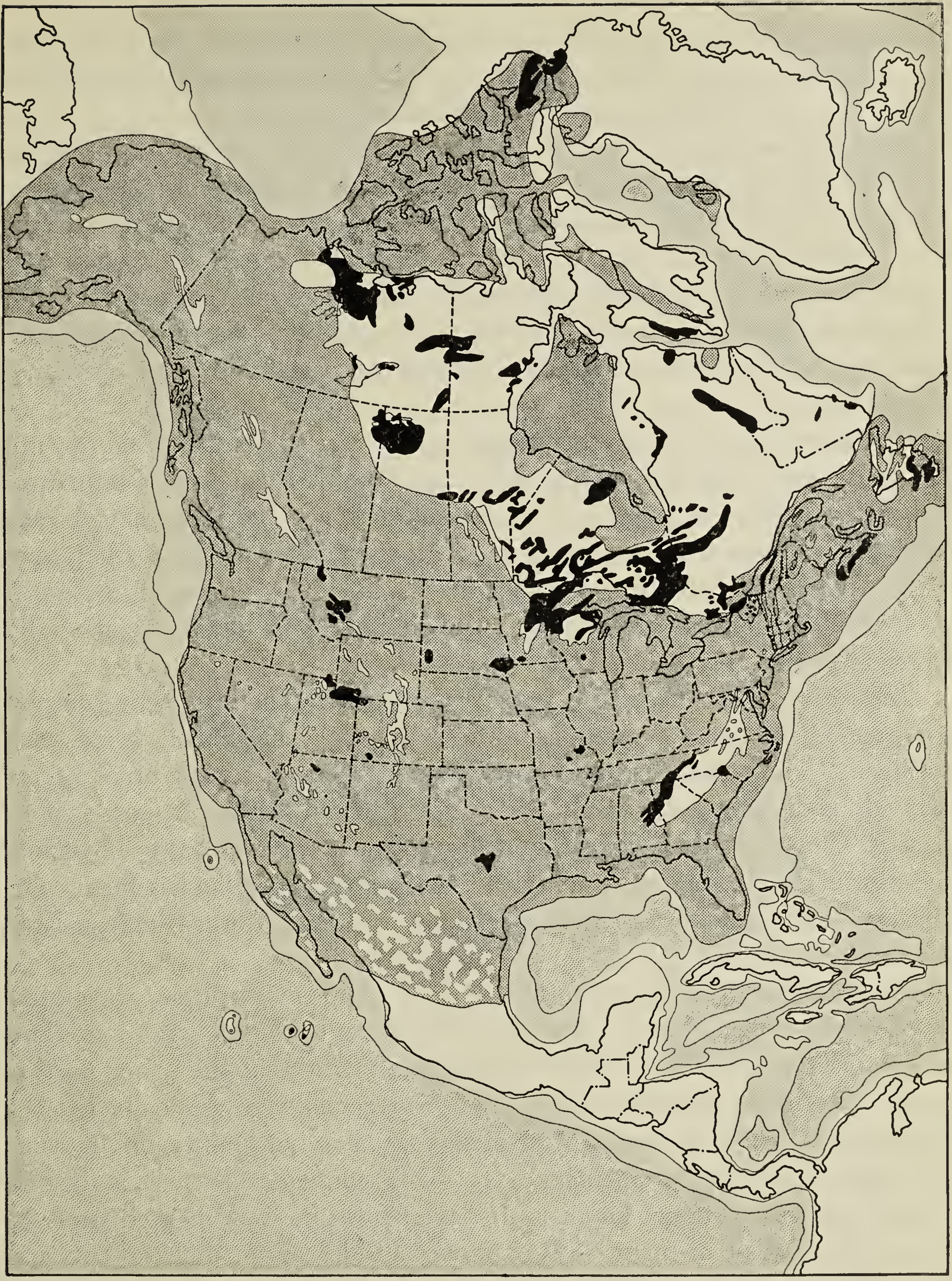
The basement complex is bared to the eroding forces of the atmosphere at many places over the continental areas of the world. Particularly is this true in Brazil, Canada, China, India, and throughout much of the continent of Africa. The white areas north of Mexico (see page 501) show the limited regions of this character exposed to the surface in North America. Elsewhere over the surface of the globe there are thousands of smaller outcroppings. One of the most familiar to residents of the United States is the hard, dark-colored, gnarled layers which form the lowest part of the Grand Canyon walls.

The structure of this basement complex, as Daly puts it, "represents one of the toughest problems of the geologist." Some progress has been made in ferreting out its early history, but the word *complex* is still a good name for it.

In general, the rocky materials that form this basement can be matched kind for kind from the rocks that make up the veneers (sedimentary deposit and lava outflow) above it. In these veneers one finds thick, water-laid beds of gravel, sand, mud, and limestone, as well as layers of lava and volcanic ash. In both the basement and the overlying layers are found invasions from below of molten granite, which further add to the confusion. Indeed, the *dominant rock of this whole series is this intrusive granite.* These intrusions and extrusions of various kinds are separated in both time and space.

Since there are sandstones, limestones, and shales in the complex, much the same agents of weathering, transport, and sedimentation that prevail today must have been at work in those distant days of the earth's history when the basement complex was forming. Little is known, however, of the prehistoric lands from which the sediments of the complex came.

In both the complex and the overlying veneer the sediments, lava, and volcanic ash have been squeezed together, reheated, and recrystallized. The recrystallization of sedimentary and igneous products under these conditions is known as metamorphism. In the veneers metamorphism is local and confined very largely to the comparatively narrow belts that form mountain chains. The basement complex, by contrast, is recrystallized almost universally throughout. Moreover, broad areas of the veneers still lie almost as they were deposited, having suffered relatively little geological disturbance.



The white areas north of Mexico indicate regions of basement-complex exposure[1]

[1] From *College Geology*, by T. C. Chamberlin and R. D. Salisbury. By permission, Henry Holt and Company.

But it is very different with the series that form the complex. Here the rocks, to quote Daly again, "have been crushed, folded, thrust together, and upended" by the distorting pressure of geological forces.

Life, such as existed when this metamorphic series was laid down, is believed to have been very primitive. Certain fossils of the simplest, blue-green algae furnish about the only direct evidence of life at all. However, the great thick beds of limestone and marble found in the complex suggest that life, even if limited to very simple forms, must have been rather abundant. The tremendous pressures of metamorphism doubtless have squeezed and distorted the fossiliferous remains for the most part far beyond semblance and recognition.

The question as to when this portion of the earth's crust was laid down is like many other questions of geological time. The time can only be estimated. On the basis of such evidence as can be collected, it is judged to have been a billion or a billion and a half years ago. Moreover, it must have taken hundreds of millions of years to accomplish the task. Some geologists estimate that about half of the earth's history was occupied with the development of this basement.

The Rock Veneers above the Basement Complex. The basement complex has been found to be continuous, either exposed or unexposed, across each continent. The veneers, however, are different. They are made up of a great many different areas, or terrains, and vary greatly in depth. At some points they are thousands of feet thick; at others they are so shallow as to be broken and discontinuous, leaving, as we have found, the rocks of the basement complex open and exposed. In Africa, the reader will recall, this is true for a large part of the continent.

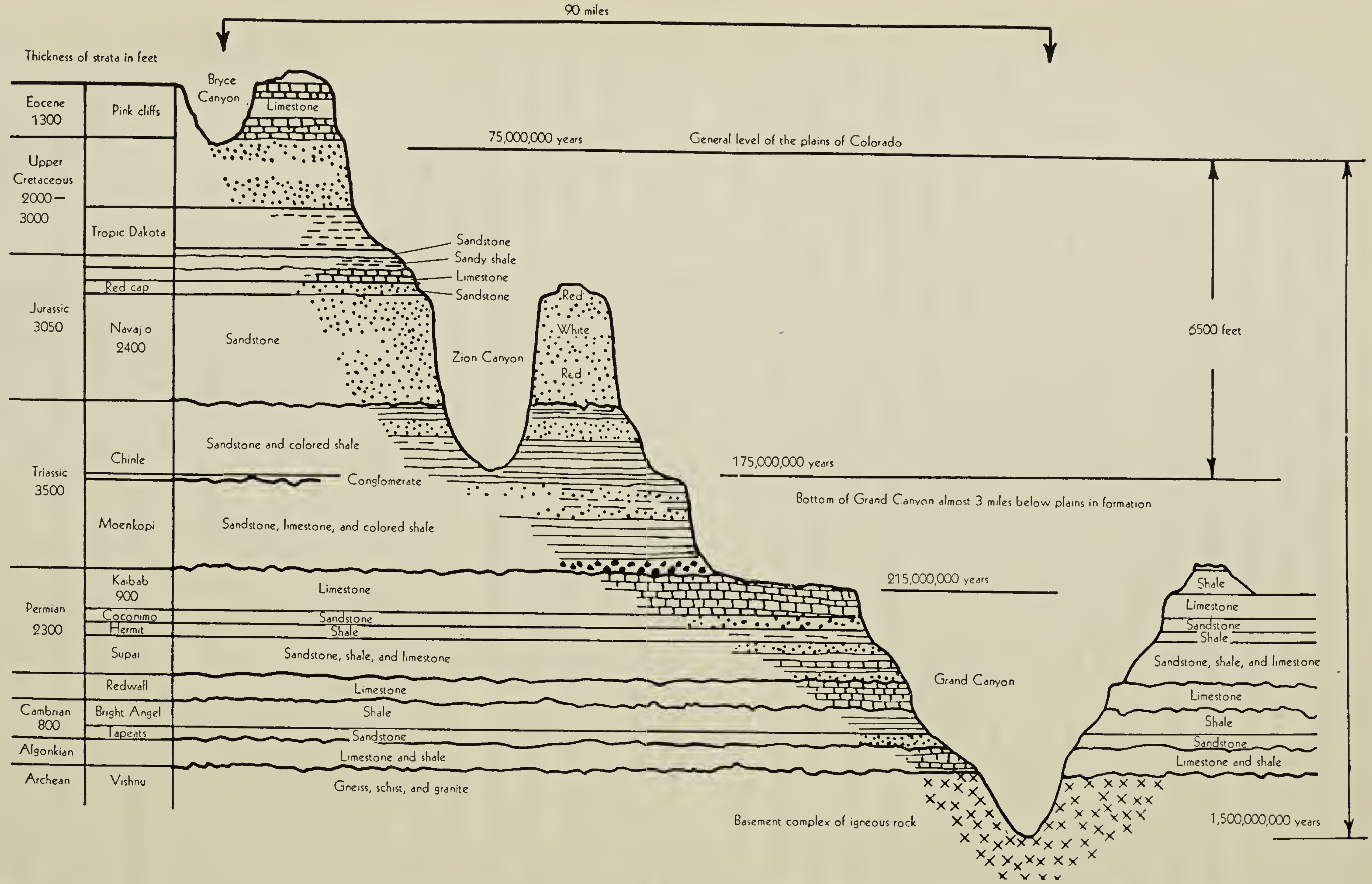
The most important of these veneers is of sedimentary origin. It is composed of the broken-down, decomposed constituents of rocks that were once molten. Thus in the last analysis it is probably true that the major portion of all rocks, from whatever source they may come, were originally igneous (Latin *ignis*, "fire") material. Most of them, too, are of granitic origin, coming chiefly from the basement granites. This sedimentary veneer is the one with which most of us are familiar. Its layers form the well-marked strata to be seen on the face of many cliffs or mountainsides. Even railroad cuts and other excavations, in a small way, frequently bear mute evidence that soil and other earth materials have been transported and deposited.

The less extensive of the two veneers, as has been pointed out, is the lava which wells up through fissures and vents from the deeper, subterranean regions of the earth. Sometimes it is intruded between the layers of the sediment. At other times it flows out in the form of great sheets over the surrounding country. Lava in Iceland in 1783, flowing from a fissure twenty miles long, spread out in a sheet seventy-five miles wide to a depth of one hundred feet. In less recent geological times the region now occupied by the conjunction of the states of California, Washington, Idaho, and Oregon was covered by a lava flow which in some places was 4000 feet thick. It extended over an area of 250,000 square miles.

The strata of the continental bucklers which we have just discussed comprise that part of the earth's crust which one can see and concerning which the geologists feel some degree of confidence. In addition, it is the portion that is more or less exposed and affected by the forces of the atmosphere and the hydrosphere. More intimately, it is the part of the earth's crust upon which practically all of our lives are spent and from which we draw sustenance. It is the Mother Earth of the naturalist and poet. For this reason the basement complex and more especially its veneers will receive most of our attention in subsequent chapters. But before we come to a closer study of the earth's outer crust, it may be of interest to consider briefly something of the earth's possible deeper internal composition and structure.

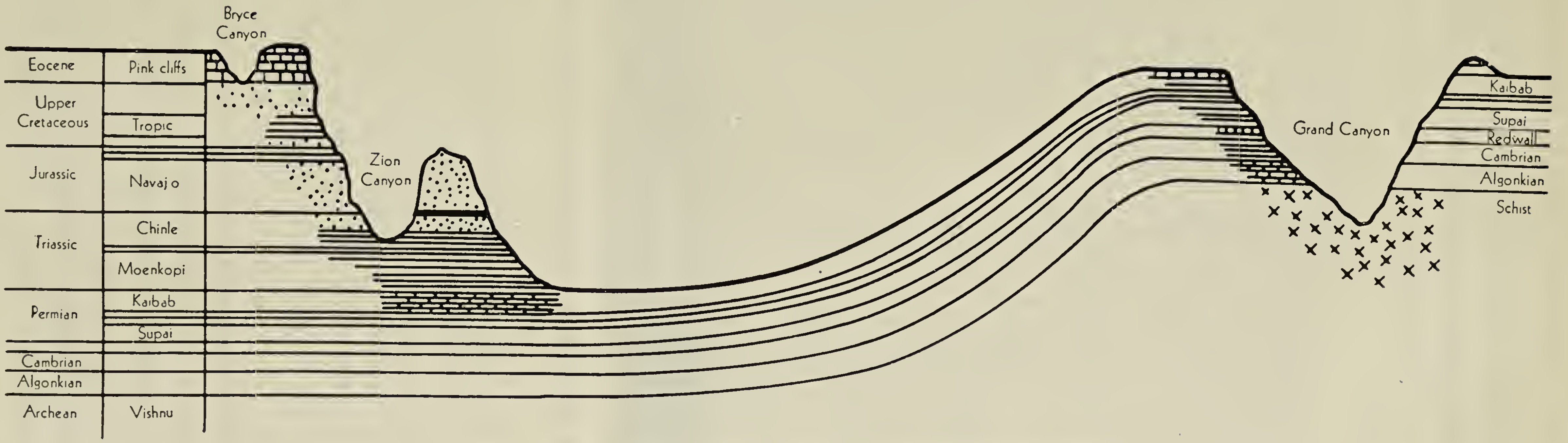
Below the Continental Blocks There Appears to Be a Basaltic Sphere. On the basis of their chemical composition the lavas have been analyzed into many different classes. But among all these erupted materials of different kinds that have been pushed up from the subterranean depths, basaltic lava forms by far the greatest volume. Basalt is a dense, fine-grained, igneous rock which is black or greenish-black in color. It stands in contrast to granite, which is another igneous rock but less dense, coarser-grained, and gray or reddish-brown in color. Because of its greater density the basalt is heavier than the granite, and upon this condition many of the relations to be considered later are believed to depend.

When geologists try to examine the deep ocean, which begins at the foot of the continental shelves, about 13,000 feet below sea level, they are seriously handicapped by the intervening water; but they are not entirely baffled, for geological forces have obligingly pushed up here and there volcanic peaks above the level of the water. The Hawaiian group, the Samoa Islands, the Society Islands, and Bermuda furnish good examples. Although the total area of such islands is small, considering the vast stretches of the sea, nevertheless they do tell an interesting story. Their composition indicates that they too have been extruded from a vast reservoir of basalt. Some islands, such as New Zealand and the Fiji group, however, have continental rock


90 miles
Thickness of strata in feet
Eocene 1300
Pink cliffs
Upper Cretaceous 2000—3000
Tropic Dakota
Jurassic 3050
Red cap
Navajo 2400
Triassic 3500
Chinle
Moenkopi
Permian 2300
Kaibab 900
Coconino
Hermit
Supai
Redwall
Cambrian 800
Bright Angel
Tapeats
Algonkian
Archean
Vishnu
Bryce Canyon
Limestone
75,000,000 years
General level of the plains of Colorado
Sandstone
Sandy shale
Limestone
Sandstone
Sandstone
Zion Canyon
Red
White
Red
6500 feet
Sandstone and colored shale
Conglomerate
Sandstone, limestone, and colored shale
175,000,000 years
Bottom of Grand Canyon almost 3 miles below plains in formation
Limestone
Sandstone
Shale
Sandstone, shale, and limestone
Limestone
Shale
Sandstone
Limestone and shale
Gneiss, schist, and granite
215,000,000 years
Grand Canyon
Basement complex of igneous rock
Shale
Limestone
Sandstone
Shale
Sandstone, shale, and limestone
Limestone
Shale
Sandstone
Limestone and shale
1,500,000,000 years

Geological section of Bryce, Zion, and Grand Canyons

Showing rock veneer above the basement complex


Bryce Canyon
Zion Canyon
Grand Canyon
Eocene
Upper Cretaceous
Jurassic
Triassic
Permian
Cambrian
Algonkian
Archean
Pink cliffs
Tropic
Navajo
Chinle
Moenkopi
Kaibab
Supai
Vishnu
Kaibab
Supai
Redwall
Cambrian
Algonkian
Schist

Topographic section of Bryce, Zion, and Grand Canyons

Showing altitude relation due to folding of the earth's crust mixed with their erupted lavas. It seems probable that such islands are but detached and isolated areas of land that was formerly part of a continent.

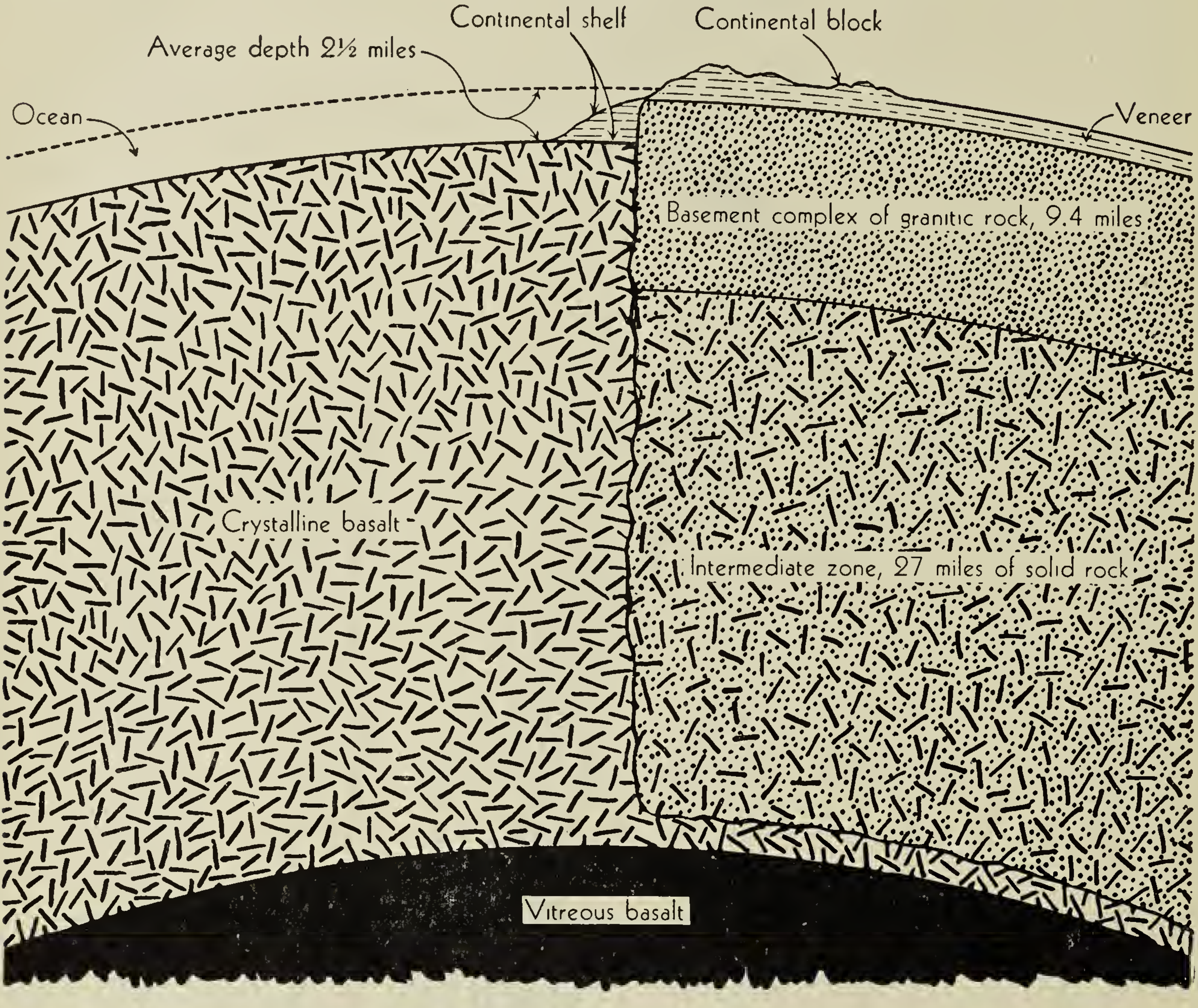
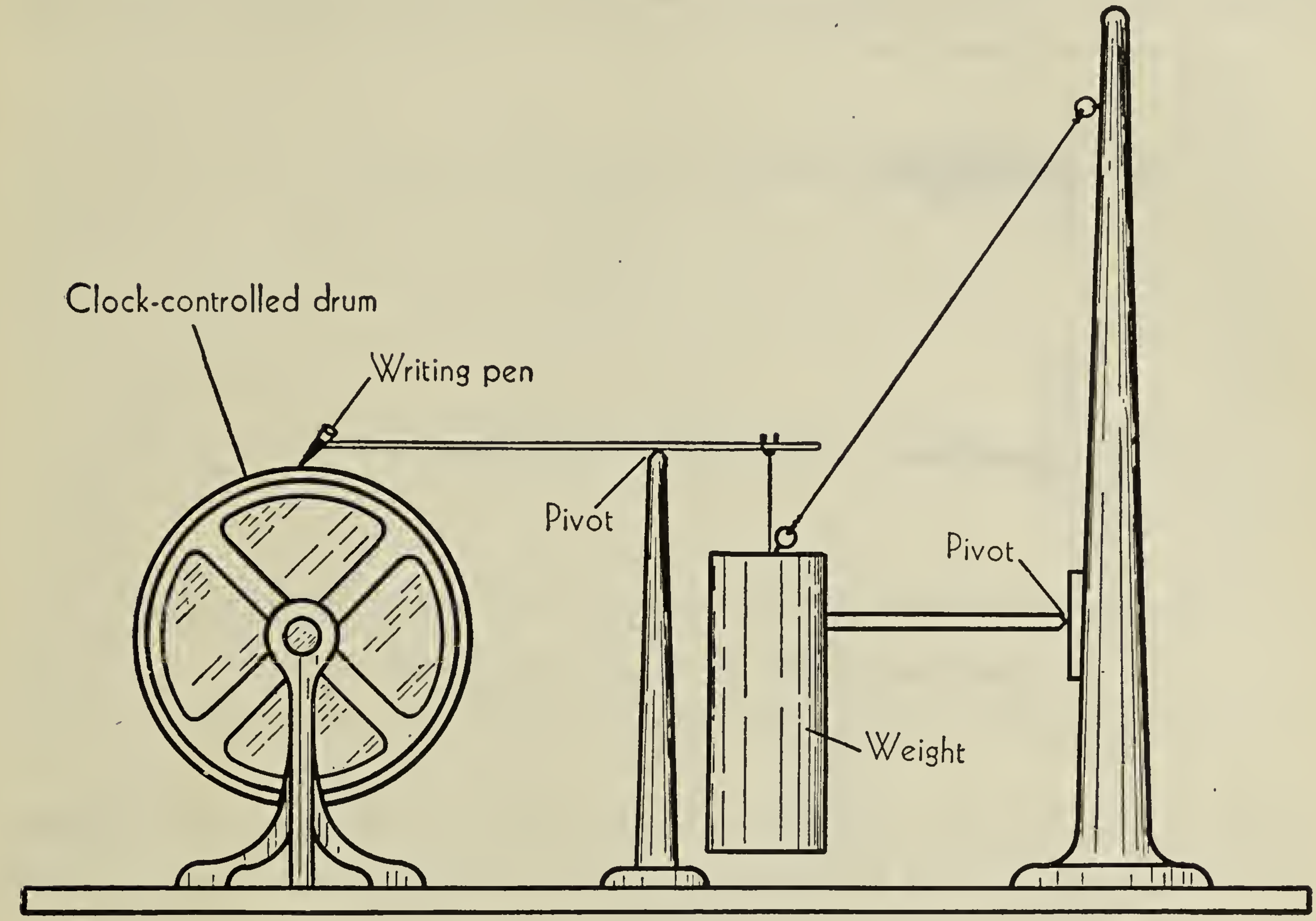

Continental shelf
Continental block
Average depth 2½ miles
Ocean
Veneer
Basement complex of granitic rock, 9.4 miles
Crystalline basalt
Intermediate zone, 27 miles of solid rock
Vitreous basalt

Diagram showing the supposed crust of the earth

These observations, then, have led many geologists to believe that below the basement complex of the continents proper there exists, what for our purpose may be considered to be, a deep layer of solid rock some 27 miles thick. The upper part of this layer is heavily charged with granitic material, while in its lower part basaltic materials predominate. Thus the veneer, the basement complex, and this 27-mile layer constitute the continental blocks.

Immediately below the continental areas there is believed to be a relatively thin layer of solidified basalt, which extends out horizontally beyond the continents and merges with the deep block of frozen basalt; the latter extends upward some 25 miles to form the ocean floors with their submerged lava outcrops, volcanic peaks, and coral reefs and atolls.

Very little of a positive character is known about the composition of the earth's crust beneath this basaltic sphere, or about how it was formed. Most geologists believe that the earth at one time was in a molten condition and that immediately below the solid crust there is still to be found a layer of vitreous basalt. This might be a residue of the old molten condition of the earth, it might be a condition maintained by the heat of compression produced at this great depth, or it might be the product of radioactive influences. This layer, in consistency, would resemble thick molten glass.



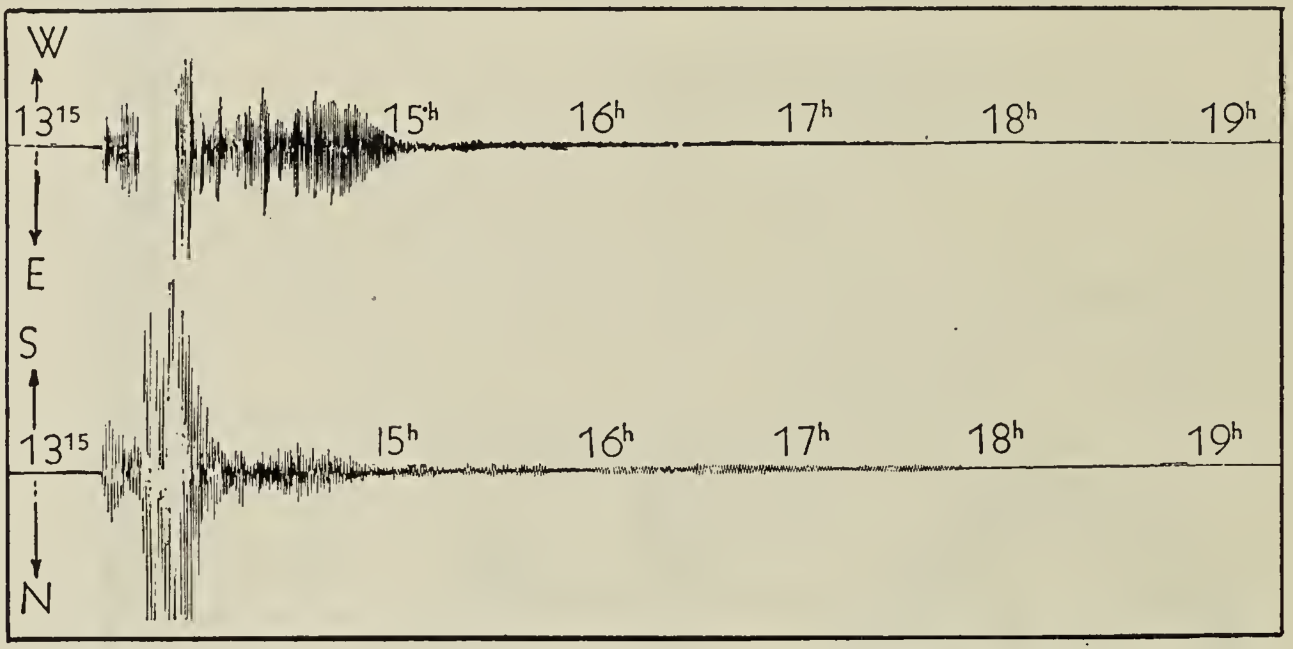
A pendulum seismograph

When vibrations of the earth occur, the weight, or pendulum, does not move as readily as the instrument, and thus causes the pen to write on the graph paper on the drum

Still other geologists believe that the earth never was liquid, but was built up by an enormous accretion of infalling planetesimals. Such zones of flowing material and the lava pockets as do exist are accounted for on the basis of heat and compression. These effects may be general or confined to particular regions.

Geologists Have Developed Unique Ways of Studying the Earth's Radial Profile. Regardless of what view is taken of the earth's origin and previous conditions, geologists agree that there are, deep down within the earth's crust, thick rather well-defined layers which manifest different physical properties. They also believe that the earth materials become denser as one proceeds from the surface toward the center.

Although scientists are cut off from direct observation of the deep subterranean parts of the earth, they are not wholly devoid of methods of probing this region. We have already learned of the chief method—that is, the use of the seismograph in geophysical explorations for oil and other minerals. The seismograph, it will be recalled, records not only the intensity of the earth tremors but the exact time of their arrival.



Carnegie Institution of Washington

A seismogram of the San Francisco earthquake of 1906

Registered by a horizontal pendulum seismograph at Irkutsk, Siberia

Whenever the earth's crust is jarred by an earthquake, volcanic eruption, or a heavy explosion, at least three kinds of waves are sent out.[1] The fastest wave runs out radially in all directions with almost the same speed that sound waves would have if they traveled through a like medium. Since this wave results in a kind of longitudinal push which tends to compress the carrying medium and then a reactive oscillation which tends toward rarefaction, it is called a *push* wave. A second effect of such a shock to the earth materials is a sort of up-and-down vibration. Here the earth particles oscillate not parallel to the push-wave path, but at right angles to it. Hence this wave is called a *shake* wave.

Shake waves and push waves travel out and down through the body of the earth in all directions from the center of disturbance. Indeed, some of them, if the quake is severe enough, will pass down through the earth and be recorded by seismographs on the opposite side. Push waves travel between 4 and 8 miles a second, depending on the medium through which they pass. Shake waves travel with a velocity of from 2.5 to 4.2 miles per second. Thus, since the duration between the arrival of the two kinds of waves increases with distance traveled, this difference furnishes data which indicate how far away the center of disturbance was.

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[1] Dr. Don Leet, director of the seismograph station at Harvard, has recently reported a new kind of surface wave which travels more slowly and is distinct from those discussed here.

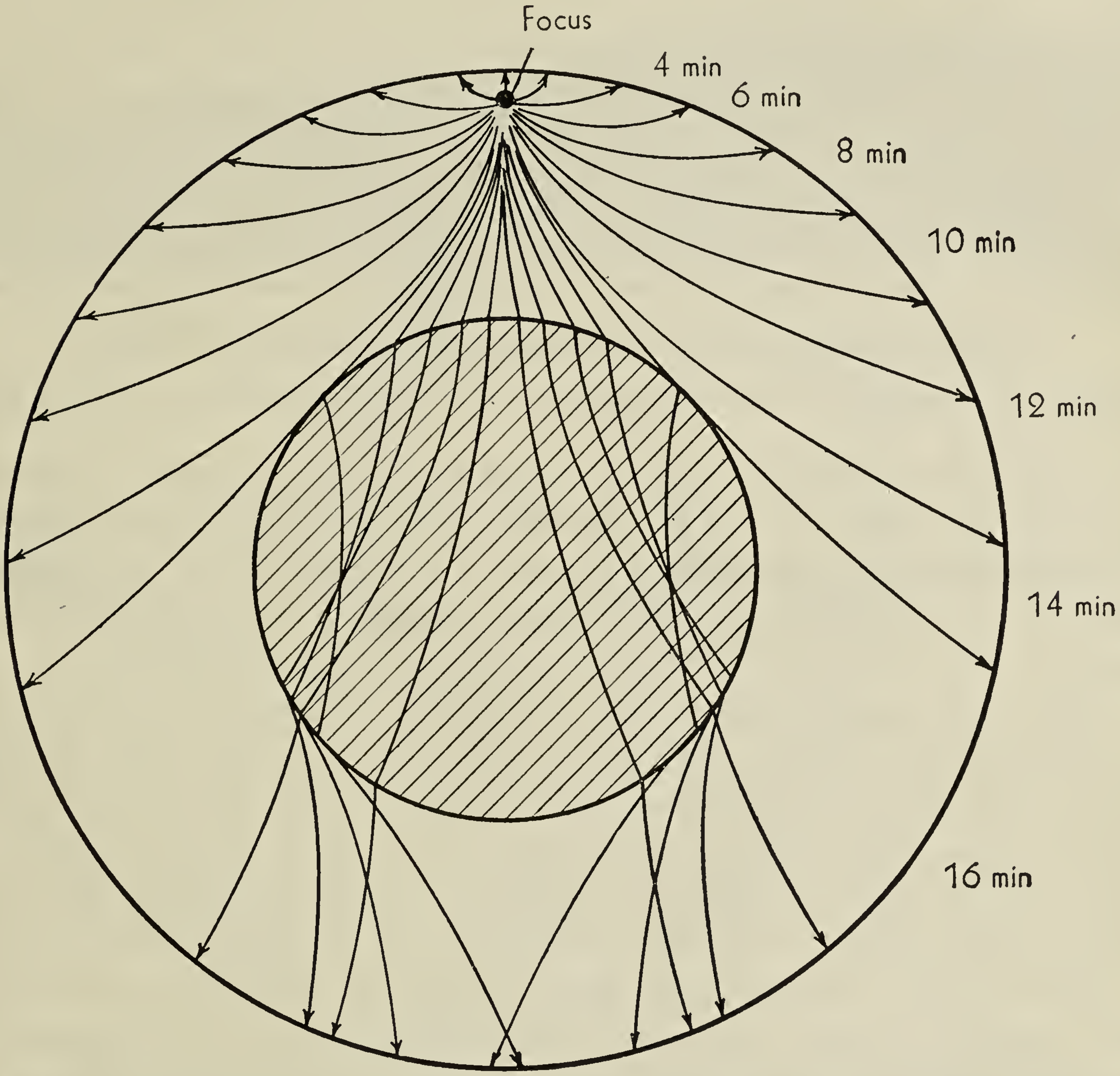


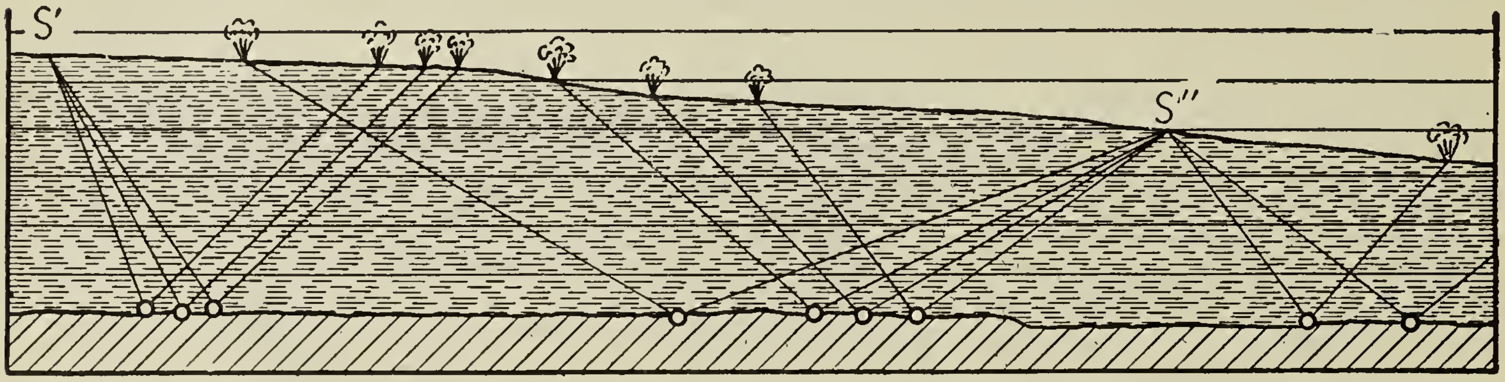
Diagram showing the path believed to be taken by earthquake waves as they pass through the earth

The figures on the right show the relative time required for the waves to be transmitted through the earth

Still slower than either of these waves is yet a third induced wave, which travels along the upper surface of the shocked layer of rock. For this reason it is known as a *surface* wave, and it travels about 2 miles per second. The seismograph record for each type of wave is generally different, the push waves producing the least violent impulses and the surface waves the most violent.

The velocity of earthquake waves through elastic rock, it has been found, depends on several factors, such as density, rigidity, and compressibility.

Other conditions, such as temperature, will also affect the wave-carrying power. Much information from this angle has already been worked out in the laboratories, with many other related investigations still in progress.



A diagram showing the method of measuring the thickness of glaciers

S′ and *S″* are seismographs. The thickness of the earth's layers is measured by the same method[1]

In our study of radiant energy we found that light rays could be reflected from a surface. Moreover, if a wave, when passing through one transparent medium, encountered another of greater or lesser density, it was bent, or refracted. Upright sticks in shallow water seem bent at the water line for this reason.

Earth waves manifest very similar properties. Within the radius of the earth, as will presently be made more definite, there appear to be relatively sharp boundaries, or curved *planes of discontinuity* as they are more accurately called. These discontinuities characterize the margins between spheres of earth materials that have different physical properties, particularly those that change, either through reflection or refraction, the direction of waves caused by earth tremors. Seismographs, then, stationed at various locations on the earth, indicate not only the center of disturbance, but, by the intensity of reception at different points, the manner in which the directional paths of the waves have been changed by these planes of discontinuity. The figures on page 509 and above afford good illustrations of this principle.

There are now more than two hundred seismograph stations in the world, which are geographically rather well distributed. Most of these are keeping continuous records of any earth disturbances that may occur. Consequently they are furnishing a large body of data which geologists, and especially seismologists, are attempting to unravel and thus determine the structure of the deep earth.

A Provisional Graphic Profile of the Earth's Interior May Be Ventured. In this connection we wish to emphasize that any picture which one forms of the earth's profile from circumference to center must be *provisional.* Points of agreement can be reached, but on many other aspects there is a rather wide divergence of opinion. However, with this fact understood, we may

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[1] From *Architecture of the Earth*, by R. A. Daly. By permission of D. Appleton-Century Company.

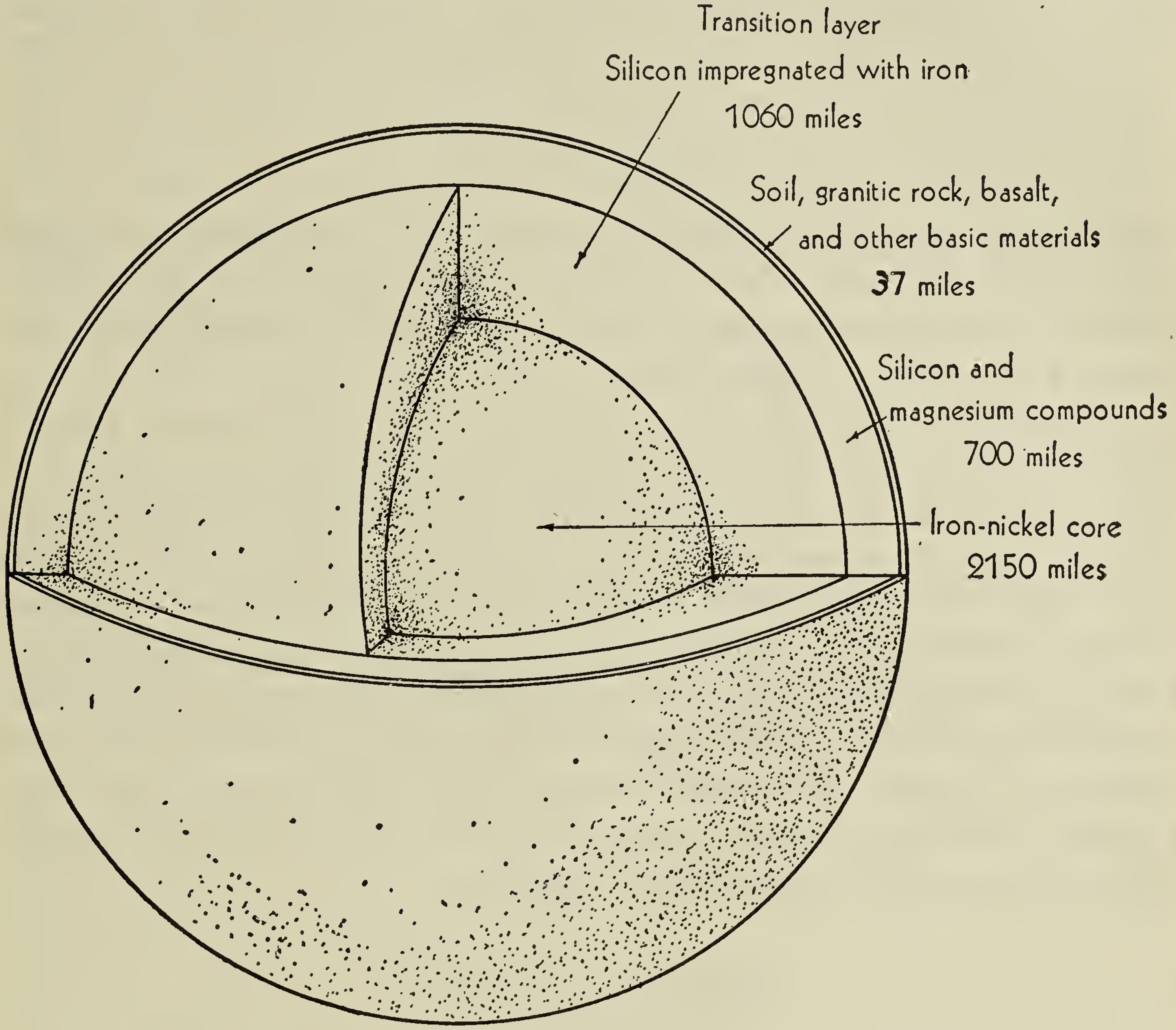
Transition layer
Silicon impregnated with iron
1060 miles
Soil, granitic rock, basalt, and other basic materials
37 miles
Silicon and magnesium compounds
700 miles
Iron-nickel core
2150 miles

Diagram to illustrate one concept of the radial structure of the earth

present the view of Ernest A. Hodgson, a Canadian geologist,[1] which will help us to form a picture of the possible situation. Subsequent research is suggesting that some changes in depth of strata may be in order, but the general view may be accepted.

By this view it is believed that the earth has an outer skinlike crust of ordinary soil, granitic rock, basalt, and other geological materials about 37 miles thick. Beneath this lies a 700-mile shell mostly of silicon and magnesium compounds. A transition layer of silicon impregnated with iron follows, the combination having a depth of about 1060 miles. Finally, a central iron-nickel core is reached with a radius of about 2150 miles.

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[1] Ernest A. Hodgson, "The Earth Beneath in the Light of Modern Seismology," *Annual Report, Smithsonian Institution, 1931*, p. 358.

Since the whole earth has a density about 5.5 times that of water, and the outer crust has a density of only 2.7, it is estimated that this inner core must be about ten times as dense as water. It would be extremely difficult to explain the density of the whole earth on any other basis. But no ordinary rock has a density nearly so high; hence geologists are driven to the metallic hypothesis for the earth's core. Also, since the heavier meteorites are of iron-nickel composition, it seems reasonable to assume that the center of the earth may be of similar character. Moreover, we have found that the earth is a huge magnet; hence the "strongly iron-center idea" might find some support from that direction also. Other substances, such as gold, silver, lead, copper, and zinc, are scattered through the mass, but, relatively speaking, do not appear in any considerable quantities.

If this idea of the radial structure of the earth is correct, the question naturally arises as to how the materials got sorted out in such a way as to present the densest at the center and the successively less dense toward the outside. It would appear as if gravity had had something to do with this result, and that is what earth scientists believe. Perhaps most of them—although holding in the main to the tidal-disruption theory regarding the formation of the solar system—believe, contrary to the views of Chamberlin and Moulton, that in its early stages the earth became a molten mass. Once molten, the materials of the earth through a long period of time would have a chance gradually to become assorted on the basis of their specific gravity. This seems to be the most plausible explanation.

Questions for Study

1. What evidences can be given from everyday life that tend to support the views of geologists regarding the internal composition of the earth?
2. What methods has man used to arrive at some idea of the internal composition of the earth?
3. What evidences, apparent all about us, tend to support the theory of the origin and composition of the basement complex?
4. In what ways are the strata of continental bucklers of importance to man?
5. What evidence has man found that tends to support the theory of a basaltic sphere below the basement complex?
6. Why is the central core of the earth believed to be of iron-nickel composition, although man has never been able to examine it at first hand?
7. The earth was once pictured as a sphere having a hard crust and a raging fiery center. Why is this picture of the center of the earth not acceptable to modern geologists?

8. How could one attempt to explain the assortment of the earth materials which scientists believe would be evident in a radial profile?

9. What evidences are there that tend to support the present belief as to the composition of the various layers from the center of the earth outward?

10. From the standpoint of the geologist, how has the earth possibly come to be as it is?

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CHAPTER TWENTY-EIGHT

The Surface of the Earth Is Continually Changing

Mantle Rock Is Heterogeneous and Varied as to Origin. The earth's outer crust is composed of three principal kinds of rock: igneous, sedimentary, and metamorphic. In addition, there is scattered over the earth a surface mass of rock debris in various states of disintegration and decomposition which is generally known as mantle rock. Mantle rock is not a kind of rock separate and distinct from the three principal kinds just mentioned. Rather it is the broken-down fragments of the harder, rocky formations underneath. It consists of a thin film, a sort of veneer, spread out over the surface of the earth and is composed of clay, sand, pebbles, and boulders, together with the decayed remains of plants and animals. Geologically mantle rock is not at first glance imposing, but biologically it makes up the soil, and this furnishes the raw materials that form the very blood and tissues of living things, as we shall see later.

In some places, such as eroded stream courses, cliffs, and mountains, the mantle rock has been wholly removed, leaving the bare bedrock exposed; in other places it may be deposited as sand and mud bars, banks of talus, sand dunes, or soil to depths of many feet. In the tropics, where decay is rapid, mantle rock may be several hundred feet deep. In the northern part of North America millions of acres are covered with mantle rock rasped off, ground up, and carried down by the great glaciers of the past. This is known as glacial drift. It consists of soil, rocks, sand, boulders, and other sediments, all commingled and spread out in sheets or dropped in great ridges as lateral and terminal moraines. The same is true for the northwestern part of Europe.

Mantle rock is continually being moved, carried here and there by wind, water, gravity, and other transporting forces of nature. It is constantly being used up to form the more permanent stratified rock of the earth, much as a brickmason uses bricks and mortar to form the courses of his wall. But its supply is ever being replenished by the decay of bedrock which is exposed to the disintegrating forces of the atmosphere by the active agents of erosion. Although the material is continuously changing, the earth will always have this mantle of broken-down and decaying geological debris.

Igneous Rock Is Considered to Be the More Fundamental Rock. Of the three more permanent kinds of rock, igneous, sedimentary, and metamorphic, igneous rock may be considered to be the more primitive and funda-

Basalt

Lava

Granite

Igneous rock

mental. Igneous rock, as has been pointed out previously, was produced by intense heat; it had its origin deep down in the interior of the earth, where high temperatures prevail. If the earth in its early period was in a molten condition, it is obvious that at that time the magma from which igneous rock was formed constituted the whole of its mass and that most other types of rock have subsequently been formed from this igneous material as a basic substance. Owing to the disintegrating forces working for aeons of time, it is probable that most of the igneous rock exposed today has been pushed up in the form of molten materials from below.

Magma, which, when hardened, forms igneous rock, is a sort of complex solution of mineral matter dissolved in other mineral matter under conditions of high temperature. It is generally commingled with great quantities of hot water vapor and other gases. It is this magma, welling up and flowing out over the surface, that constitutes lava. If it contains so much hot, expanding gas that it is blown out from the mouths of volcanoes, with great explosive force, in the form of spray and congealed before it falls, it then forms volcanic ash or dust.

Igneous rocks have no regular stratified formation. Sometimes they appear to be layered, but this is due only to the fact that successive lava sheets have overflowed one another and hardened at different times. They contain no fossils, for it is obvious that no life could exist in the infernos from which igneous rock wells forth.

As has been pointed out, the two principal kinds of igneous rock that form the greater part of the earth's outer crust are granite and basalt. Granite is a composite of quartz, feldspar, and either mica or hornblende intimately intermingled, interlocked, and hardened together. If the granite-forming magmas cool very slowly, the mineral crystals are large, and the granite is coarse; if they cool more rapidly, the resulting crystals are smaller, and the texture is finer. The various shades of color in which the granite rocks appear are due mostly to the color of the feldspar or the inclusion of other minerals.

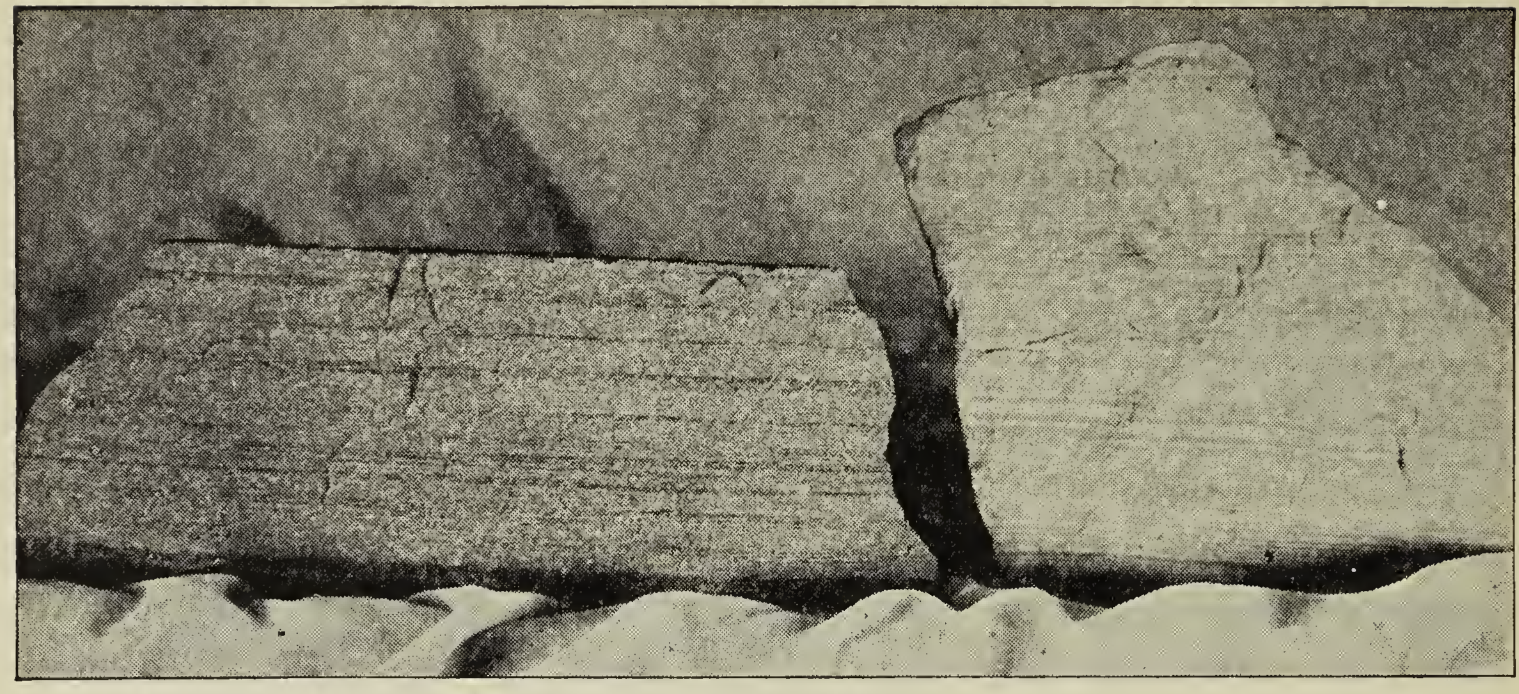
Basalt, speaking generally, is a dark, compact rock which appears almost homogeneous in structure because of the minuteness of its crystals. The latter are so small that it requires a microscope to reveal their presence. Basaltic magmas in general contain much less silica than the granitic magmas and a good many more minerals containing lime, magnesia, and iron. They flow more readily and are inclined to spread out in thinner sheets and cool more quickly.

As a class, the basalts are considerably heavier than the granites, the former having an average specific gravity of about 3.0, whereas that of the granites is about 2.67. The basalts form most of the igneous beds of the deep sea, whereas the lighter granites form much of the basement complex of the continents. Indeed, perhaps the sinking of the relatively heavy basaltic floor of the oceans has gradually pushed up the relatively less dense areas of the continents. The Rocky Mountains, for instance, are for the most part vast ridges of granite pushed up from far below.

Sedimentary Rock Is Stratified and Is the Product of Transportation and Deposit. Sedimentary rock is often spoken of as stratified rock because it is laid down in the form of layers. It is deposited mostly by water and consists of geological surface debris of all kinds. Bits of igneous rock, sand, gravel, soil, pebbles, limestone fragments,—in fact, anything that can be carried by nature's transporting agents,—are the materials out of which the sedimentary formations are built up. Sedimentary rocks appear in layers chiefly because of the sorting effects of water. When the water flowing down a young river course brings its load of debris both in solution and suspension from the elevated headlands, it drops the heavy gravel first; the sand farther down, where the flow slows up because of reduced gradient; and, finally, its mud and silt near the river's mouth or at the edge of the receiving ocean. These places of deposit would always continue if the fall of the river remained the same; but the carving, transporting action of water is constantly changing the gradient of the river bed from the first day of its existence. When the river is young, the pitch of flow is steep, and the heavier materials, such as gravel and sand, are carried far down its course, while the lighter sand and silt are carried still farther. However, as the headlands are cut down, the current is slowed up, and the heavier materials are dropped nearer to the stream's source. This means that the beds of sand first deposited will now be covered with mud and that their difference in texture will form two distinct layers, the bottom one of sand and the upper one of silt. The first layer of gravel will in turn be covered with sand, and so on for the whole series. Between these successive deposits the lines of demarcation often will not be sharp, but the layers will appear. Freshets and floods, the difference in the character and color of the rock plowed out near the headwaters, as well as other factors, give sedimentary rock a stratified character which reveals its origin.

Limestone, a sedimentary rock filled with shells

As one layer is deposited upon another the added weight compacts the lower ones, and the dissolved minerals carried by the percolating waters cement the component parts together into a rocky mass. Sedimentary rocks vary greatly in thickness, ranging from none at all, where erosion has long been active, to an estimated maximum of thousands of feet. It has been computed that had no secondary erosion taken place, the total thickness of sedimentary rock would be approximately three hundred and fifty thousand feet. The



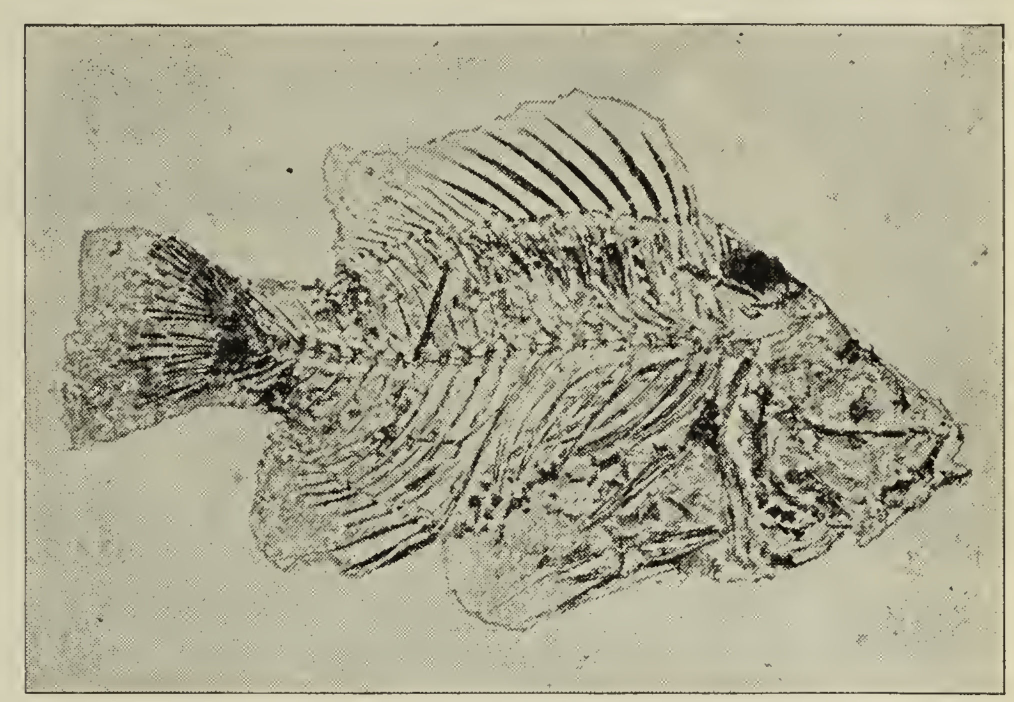
Sedimentary rock: laminated sandstone

strata formed are named according to the materials built into them. The principal ones are conglomerates, sandstone, shale, and limestone.

Conglomerates usually consist of rounded pebbles of granite, limestone, or quartz bound together by a matrix of cemented sand. Sandstones, as the name indicates, consist of sand which is mostly the tiny quartz fragments from disintegrated granite. This sand is deposited mostly in relatively shallow seas. The particles are compacted and cemented together by silica and other binding materials which have been deposited between the grains by the action of water. Shale is the indurated product of silt and clay layers. These hardened strata of clay and mud are usually highly laminated and split easily into platelike slabs.

A highly important component of sedimentary rock is the fossils they contain. The word *fossil* comes from the Latin *fossus*, which is the past participle of the verb meaning "to dig." Fossils are therefore the excavated remains of living things. Sometimes they consist of the actual resistant portions, such as teeth, bones, scales, and shells, of the organic body itself; but perhaps more often they are formed of the limy or siliceous casts of these parts. After perishing, the organism became buried deep enough to form a mold of its more resistant parts. Then, by decay or the dissolving action of water, the organic material itself was slowly removed molecule by molecule while other percolating water-borne minerals were simultaneously deposited in their place. The result was a replacement of the organic object so faithful as to preserve in exact detail the structure of the original body. It is in this way that the petrified forests and stumps are formed which reproduce the very grain of the wood itself.

Limestone is also an important product of sedimentation. It consists chiefly of the indurated remains of mollusks, coral, and many other invertebrate shells laid down as a calcium carbonate deposit. In some places it may be hundreds of feet deep, as around the rims of atolls and along coral reefs. Chalky deposits are formed in this way.



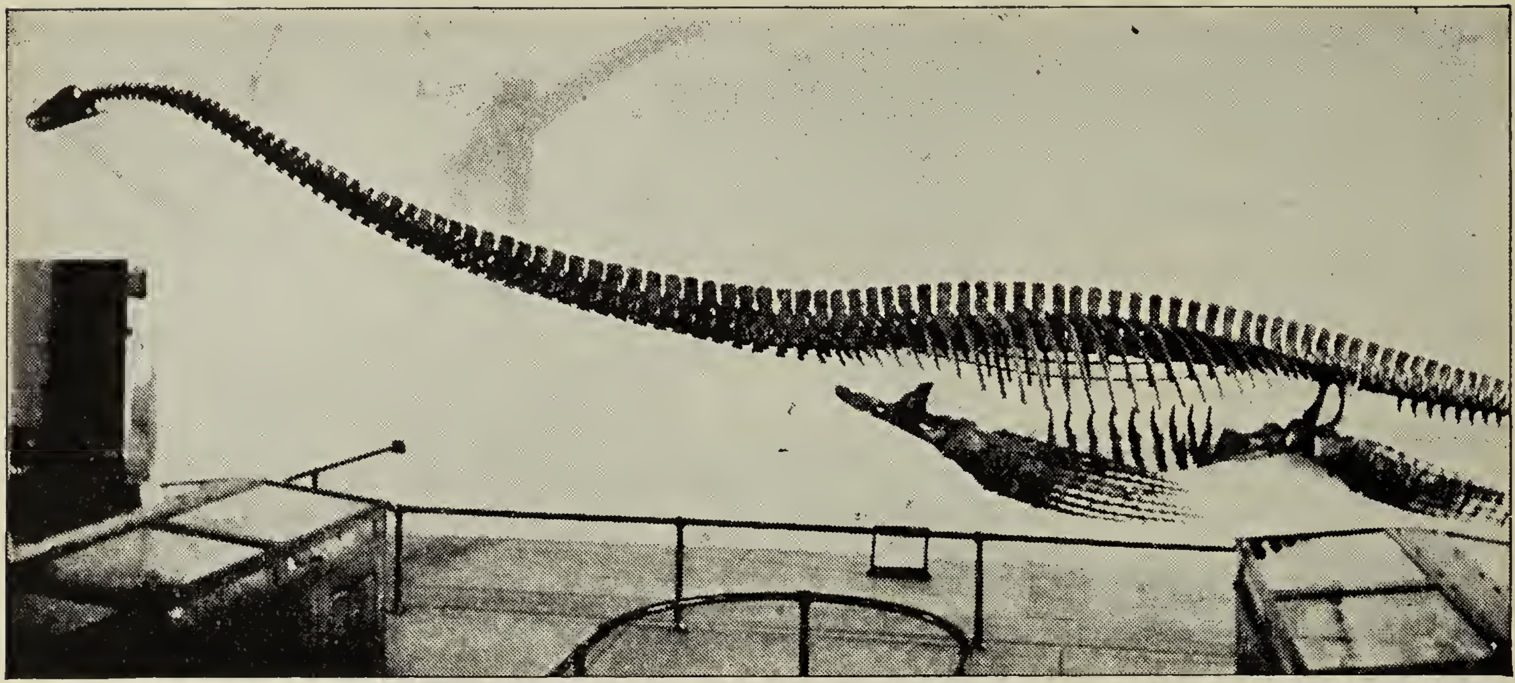
A fossil fish found in sandstone shale

Metamorphic Rocks Are Derived from Igneous and Sedimentary Rocks. Metamorphic rocks are not a type of mineral deposit separate and distinct from igneous and sedimentary rocks. On the contrary, igneous and sedimentary rocks furnish the very materials upon which the geological forces of nature work to produce metamorphic rocks. The word *metamorphic* itself means "beyond form" and indicates that the original igneous and stratified deposits have been worked upon in such a manner as to carry them beyond the form in which they originally appeared. These rocks are also recrystallized.

The principal forces involved in metamorphism are pressure and heat, acting usually in conjunction with water and gases. The original rocks are not melted in the process, but the tremendous pressures and temperatures applied cause the old characters to pass over, by transition, into new ones.

The conspicuous feature of metamorphic rocks is their crystalline condition and tendency to cleave along certain planes. This must not be confused with layering produced by sedimentation. Rather it is a result of the changes which the rock has undergone during the metamorphic processes.

Slate is an example of metamorphic rock familiar to everyone. It is the product of metamorphosed shale, and its hard, smooth character, together with its separating lines of cleavage, constitutes its outstanding property. Starting with mud flats deposited through sedimentation, the enormous and persistent geological forces of superimposed layers augmented by shears and strains and in some cases by volcanic heat have slowly transformed the original mud into indurated shales and then into sheets of beautifully laminated slate. When properly surfaced and mounted, the sheets of this material form the smooth blackboards used widely in classrooms today.



A. M. Ferguson, Colorado Museum of Natural History

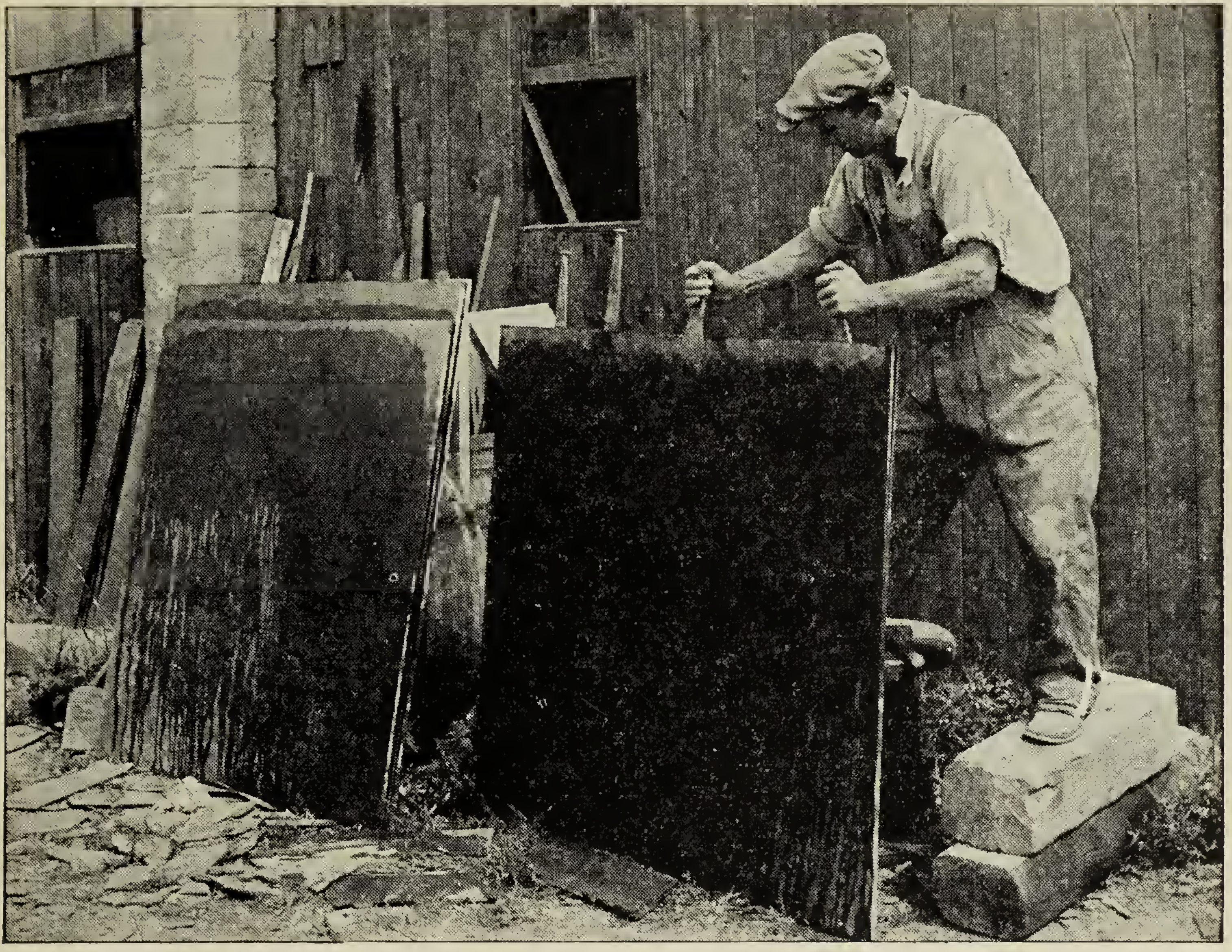
A fossil plesiosaur from the sedimentary deposits in Colorado

Marble is also one of the important products of metamorphosis and is derived from limestone. Generally the fossil shells and unattractive features of ordinary limestone are effaced in the process, and the calcite crystals are brought out in a form visible to the unaided eye. Pure marble is white, but the inclusion of impurities often gives it a banded and mottled appearance of great beauty. The red and yellow tones are due to the presence of iron compounds, and the grays and blacks are produced by the inclusion of organic matter. Anthracite is another important natural product formed by the forces of metamorphism.

It has been estimated that the sedimentary and metamorphic rock, if evenly distributed over the earth's surface, would form a layer about thirty-seven miles thick. Igneous material would then make up the rest of the planet.

The Process of Gradation Is Continually Changing the Surface of the Earth. It is rather difficult to conceive a process which works so slowly that during the whole period of human history no outstanding change has been effected in the general contour of the earth. The famous Greek Parthenon commanded a sweeping view from the top of the rocky Acropolis. That historic edifice is in ruins, but the Acropolis still stands. The Pillars of Hercules, which guard the Strait of Gibraltar, are essentially the same as when the military eye of man first surveyed them. The Himalayas, the Alps, the Apennines, and the Pyrenees have changed but little within historic times. Indeed, travelers today use the same mountain passes that Hannibal followed in his proposed assault on Rome.

Notwithstanding this apparent permanence, the surface of the earth does change. The earth is a dynamic body. Rocks are not mute monuments of an



Slate being split

unaltered stability. Instead they are the inert pages upon which the record of geological forces acting in the past and today is inscribed. Every scaly boulder, talus slope, cutting stream, mud flat, and plowing glacier is an unimpeachable witness of this continuous change. The rate of change, relatively speaking, is slow, and it is probably as rapid today as at any time during the earth's history; but the hills do change, and the poet Tennyson was uttering a profound geological truth when he wrote,

> The hills are shadows and they flow
> From form to form, and nothing stands;
> They melt like mist, the solid lands,
> Like clouds they shape themselves and go.

One of the slow but unfailing processes that are effecting these surface changes is *gradation.* In the sense in which we use it, the term includes not only the degradation, or wearing down, of rocks by various natural agencies, but the transportation and deposit of the weathered and eroded material as well.

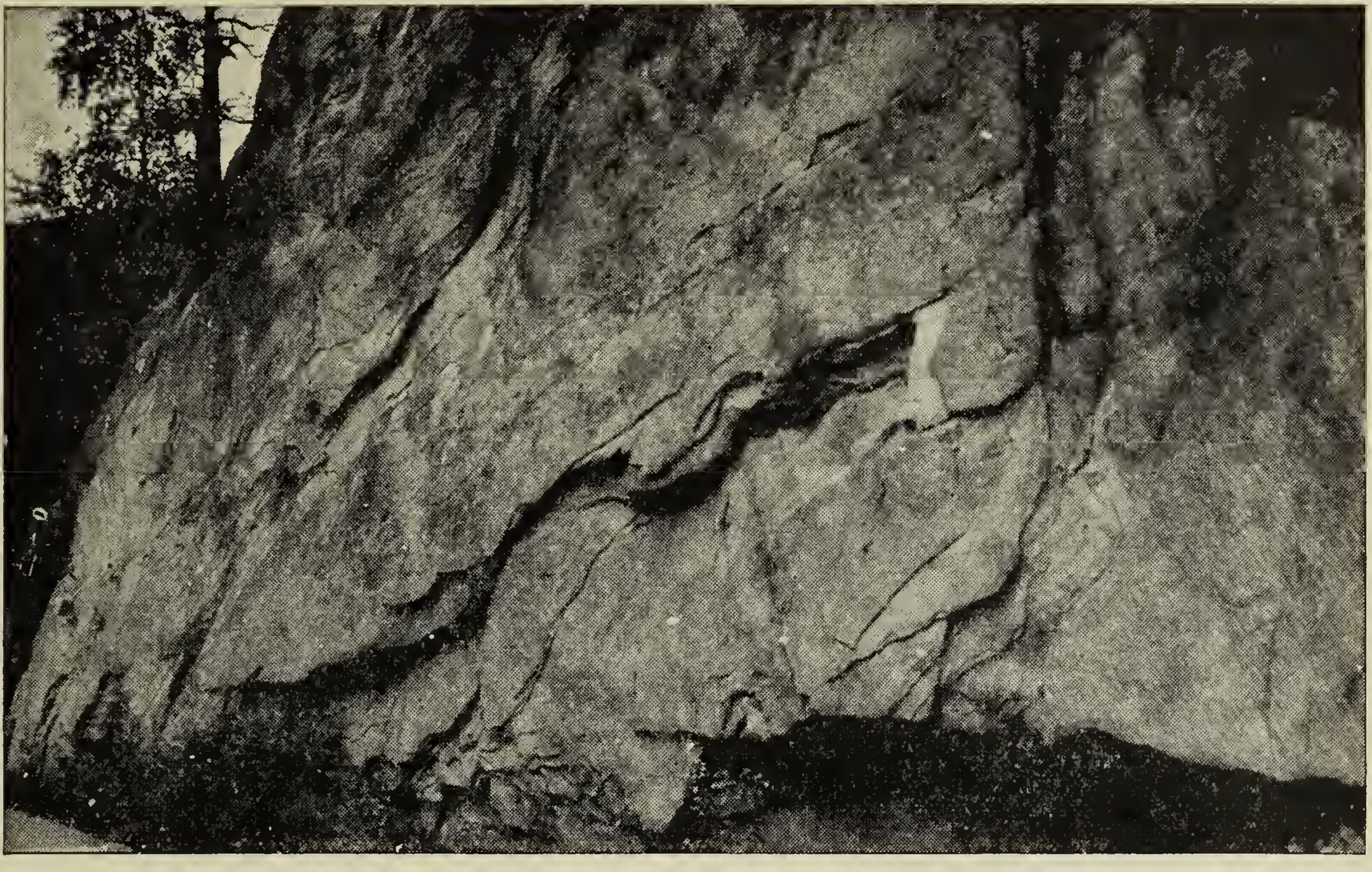
Weathering Acts as an Agent to Effect Gradation. One of the most active agents in promoting surface geological changes is weathering. This process, as the name indicates, is one in which those atmospheric agencies are active which one commonly associates with the weather. It has two aspects: mechanical and chemical.

Mechanical weathering makes its attack upon the exposed surface materials by breaking larger rocks into smaller ones. It is commonly called *disintegration.* This term is applicable whether a massive rock weighing tons is broken into other less massive rocks, or whether a tiny grain of sand is ground into microscopic bits.

Heat is one of the active factors in mechanical weathering. Rocks are poor conductors of heat; so during the daytime the extremely hot sun may raise the surface temperature of the rocks to from 150° F to 160° F. This rise in temperature causes the outer part of the rock to expand and to set up terrific strains within that tend to break it. An example of the disastrous force of such strains is shown when hot water is poured on thick glassware. At night the outer part of the rock cools down more rapidly than the deeper part, which has been heated up gradually during the day. This sets up strains in the opposite direction. Finally, the rock structure weakens under this unequal and alternating expansion and contraction and is torn away bit by bit. The greater the variation between the day and night temperatures, the more rapidly do the mills of nature grind. Exposed upstanding rock masses have their corners chipped off first. Later, thin shells peel off from the exposed curved face, much like the wrappings from a package, leaving new surfaces exposed to the subsequent effects of the same forces. Thus boulders gradually slough off, assume the rounded form, and ultimately disappear.

In the Sahara the thermometer often falls 110 to 130 degrees Fahrenheit between midafternoon and the coolest time of night. Livingstone, the famous explorer, is said to have observed that rock surfaces were heated as high as 137° F by the blazing African sun. Then, owing to rapid night cooling, angular corners weighing as much as two hundred pounds might spall off with a loud report. Prospectors among the desert Arizona mountains report hearing crackling noises as layers from one eighth to an inch or more in thickness split off from rapidly cooling stones.

Temperature changes also act as a disintegrating agent through the expansion and contraction of water. Water in freezing expands about one eleventh of its volume. The force exerted in this way may amount to two thousand pounds per square inch. Rocks are usually more or less porous. They are also full of tiny cracks, chinks, and crevices, many of which are pro-



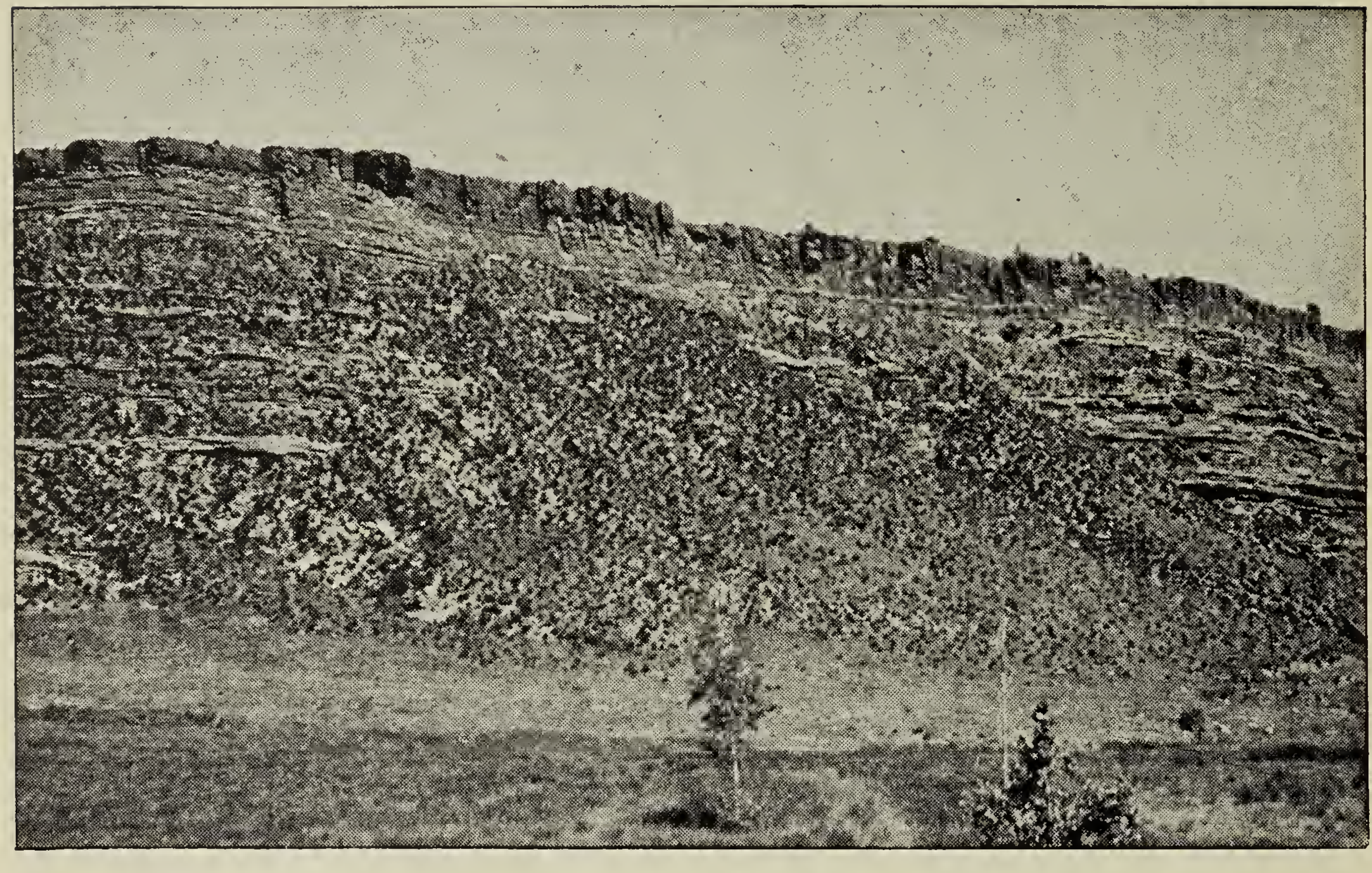
Granite rocks exposed to the heat of the sun scale off

duced by the temperature changes already noted. The water from rain and melting snow trickles down into and fills up these niches. Subsequently, during cold nights, the water freezes and expands, having much the same effect as a driven wedge. Travelers over mountainous roads in the springtime know that they are likely to find the highways obstructed by large boulders and rocks which have been loosened in this manner and then have rolled down from their original positions above.

In the same manner soils, particularly in fall-plowed fields in the north-central and eastern parts of the United States, may "heave" by freezing. Thus the roots of winter crops, such as wheat and rye, when the deeper portions are solidly frozen into the subsoil, may be broken near the surface. In this way the plants may be greatly injured.

Through the action of these forces surface rocks are gradually flaked off and broken into fragments. The resulting disintegrated mass is called *talus*. Under the action of gravity it accumulates at the base of a mountain or cliff to form a talus slope. Many of the slopes of the Rocky Mountains, particularly the Pikes Peak region, are covered with talus material.

Plants and animals may also play a prominent part in mechanical weathering. Plant roots constantly produce mechanical forces sufficient to assist in splitting the rocks among which they grow and to help in tearing them down.

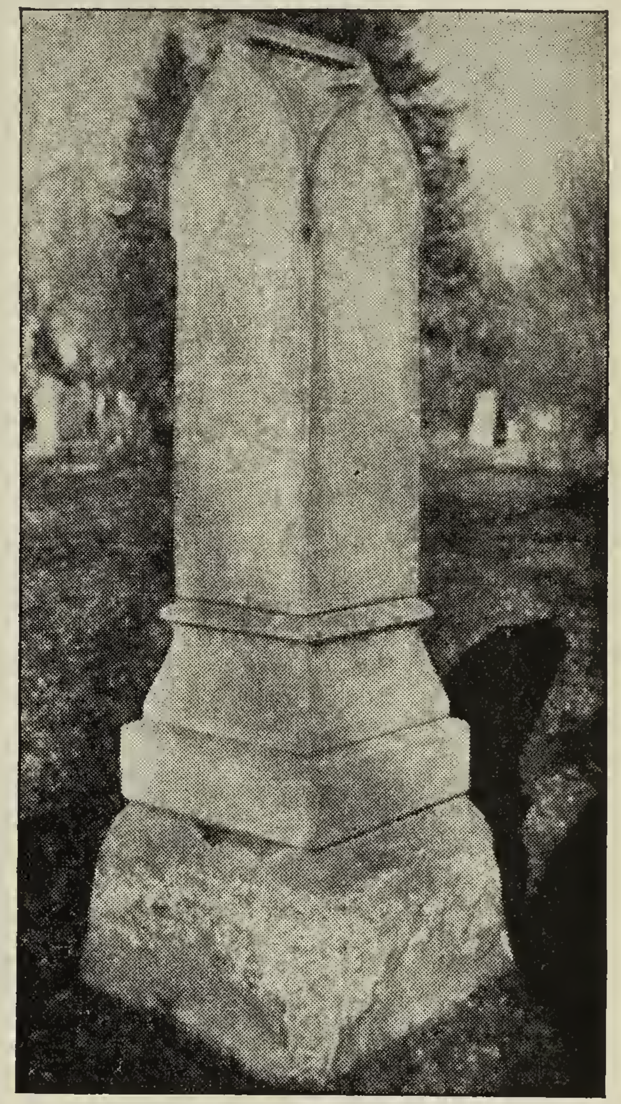


A talus slope at the foot of a cliff of sedimentary rock

The roots of plants necessarily must have an astonishingly great pushing and crowding force. The roots of the garden pea, for instance, have been estimated to have a wedging force of from two hundred to three hundred pounds per square inch. Roots growing in rocky places force themselves into cracks and crevices in the rocks. First they push in as tiny, slender rootlets; then, as they increase in diameter by growth, they come to exert a tremendous cleaving force. In the Rocky Mountains it is not uncommon to see large granite boulders split in two by the wedging roots of the forest trees.

Chemical weathering is also a very active force in gradation. It is commonly known as *decomposition* and is concerned with the breaking down of molecules and the re-forming of them into different substances. In short, it results in the disappearance of one kind of rock and the appearance of other substances in its stead.

The three chief types of reactions involved in decomposition are oxidations, hydrations, and carbonations. Rocks containing a high percentage of iron, for example, have the iron readily oxidized into iron rust when they are exposed to the weather, and this in turn hastens their further disintegration and decomposition. It is for this reason that many low-grade granites containing iron do not make good monument stones. Even though highly polished to begin with, the iron quickly oxidizes out, leaving the surface discolored and pitted. The oxidation of pyrites, which are composed of iron and sulfur, leads to the formation of sulfuric acid, which readily attacks rocks and develops solution pits. For this reason stone containing even a small amount of pyrite is undesirable for building purposes. Certain slate shingles in time show a change in color from gray or green to brown. This is due to the rusting, or oxidation, of their iron component.

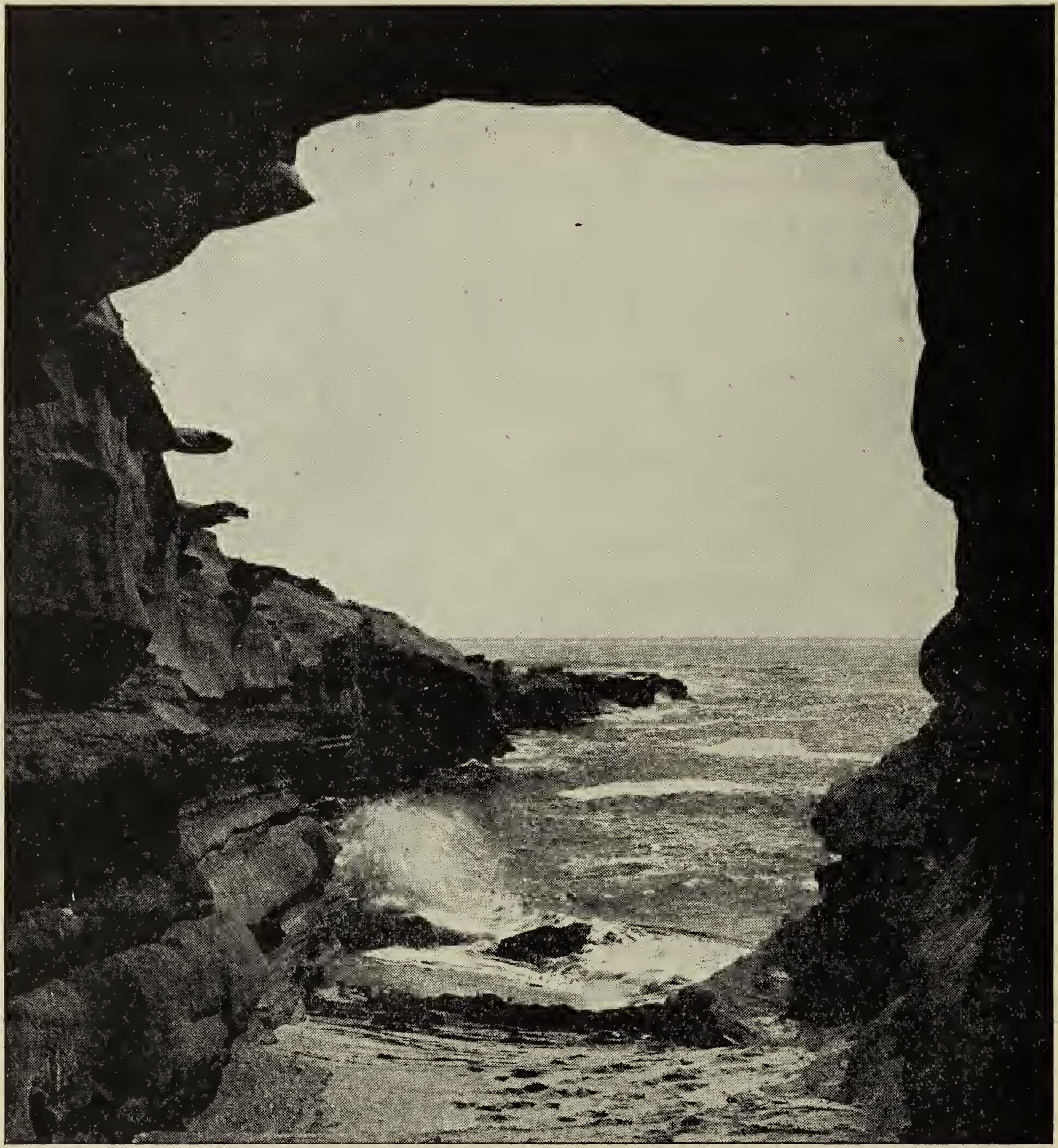


The sandstone base of this monument weathers more rapidly than the marble top portion

Hydration involves the chemical addition of water to the mineral constituents of rocks. The minerals which hydrate are chiefly certain types of silicates and oxides. Should a mineral containing calcium oxide, for instance, be moistened with water, the latter readily enters into chemical union with the oxide. In this case the change is identical with that taking place when lime is slaked by adding water to form the base for certain kinds of wall plaster.

Carbonations, however, are perhaps the most important and extensive reactions connected with rock decomposition in all nature. The carbon dioxide of the air readily unites with water to form carbonic acid. The weak acid formed in this way attacks a great variety of rocks, reducing them to simpler and usually much more soluble compounds. The oxides of calcium, magnesium, sodium, and potassium are especially susceptible to chemical reactions of this kind.

Although the process of weathering is slow, its effects are sure. Moreover, in time it produces far-reaching changes. Visitors to the historic Trinity Churchyard in New York City find there the graves of many notables. Among them are those of James Lawrence, Robert Fulton, and Alexander Hamilton. Although the inscriptions on the headstones which mark these graves were doubtless clearly formed less than two centuries ago, most of them today can hardly be deciphered. Such are the weathering effects of time. When the duration is stretched into geological periods, the effects of weathering become almost astonishing. Granitic rocks in the District of Columbia are decayed to a depth of eighty feet. Near Atlanta, Georgia, the depth of the

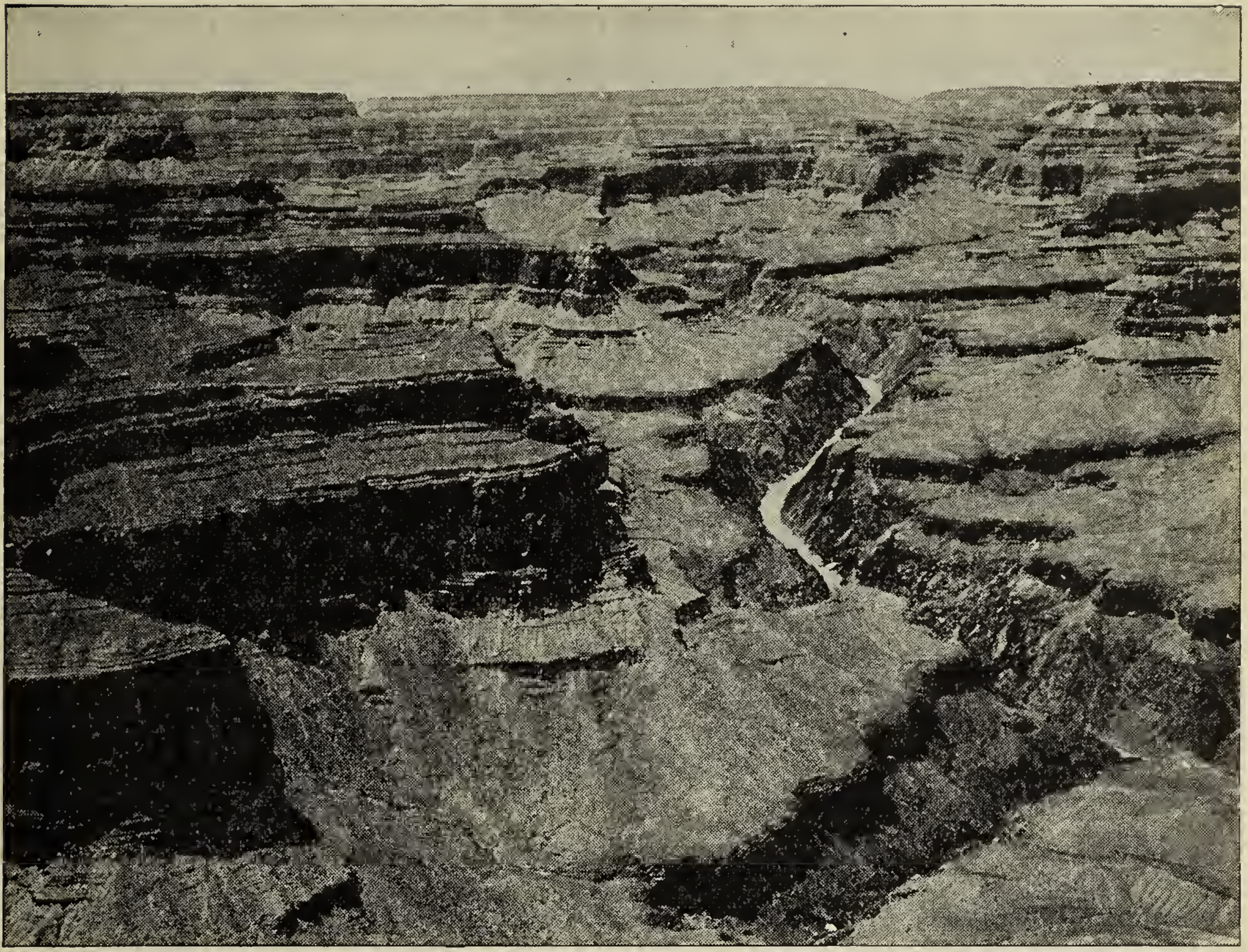


International Art Prints

Water has worn great caverns in the rocky coast at La Jolla, California

residues of similar rocks reaches one hundred feet, while the decomposed limestone in northwest Georgia forms a layer two hundred feet thick.

Erosion and Transportation Are Highly Effective Agents in Gradation. The processes of erosion and transportation are the more obvious ones in gradation. They plow off and abrade both the mantle debris and the more stable sedimentary and metamorphic rocks. Not only do these processes dislodge almost unbelievable quantities of rock and earth, but they transport them about from place to place over the earth's surface. In this way the high



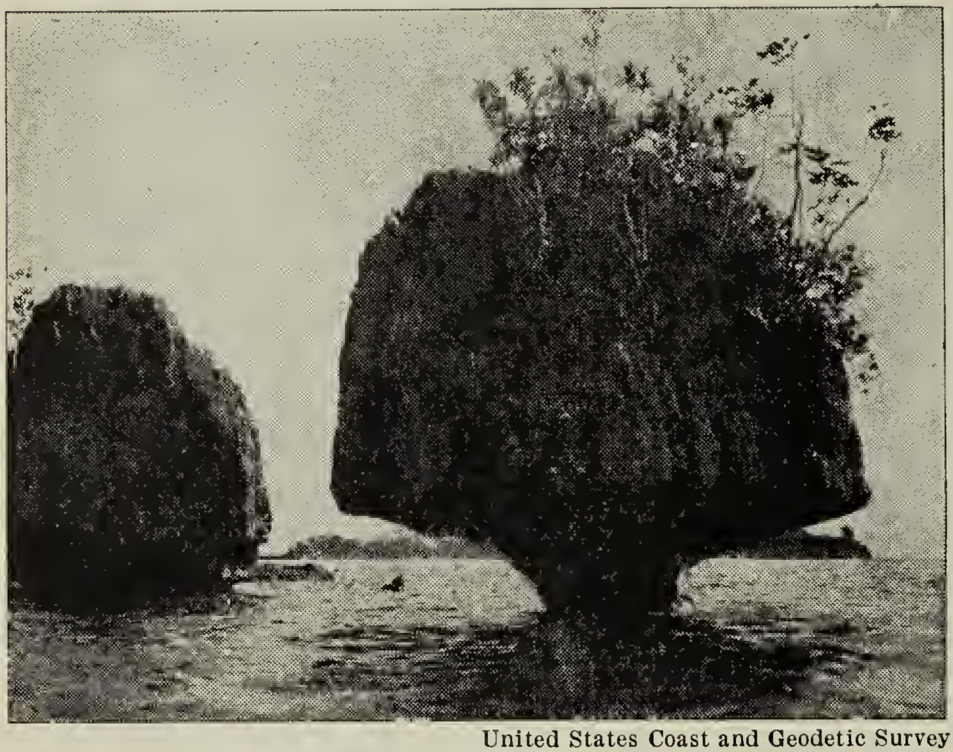
United States Department of the Interior

The Colorado River has carved away the material that once filled the Grand Canyon

places tend to be planed off and the low places to be filled in. The most active agents in erosion and transportation are water, wind, and ice.

Water as an Eroding Agent. Running water is doubtless the most active agent of erosion and transportation. The average annual rainfall over the earth is approximately three feet. At this rate a layer of water a mile deep would fall in about eighteen hundred years. Falling on the higher levels, the water collects into rivulets, which converge into larger streams, and these flow together to form rivers. The rivers then relentlessly follow their chosen courses down the continental slopes to the sea, perhaps hundreds or thousands of miles away. After heavy rains or during floods the amount of material eroded, carried down, and deposited by such streams is enormous. To bring the matter closer home, every tiny muddy rivulet running along the street curb after a shower is an exhibition of the same eroding process on a small scale.

Although the force of running water is increased as the square of the velocity, its eroding power seems to be multiplied much more. It has been estimated that the transporting power of flowing water is increased sixty-four-fold every time its velocity is doubled. During floods, such as the one at Johnstown, Pennsylvania, in 1889, caused by the breaking of a reservoir, railway locomotives have been thrown from their tracks and pushed about by the rushing waters. The erosive effect of running water is also illustrated by the fact that pebbles and small boulders in the courses of streams present well-rounded corners.

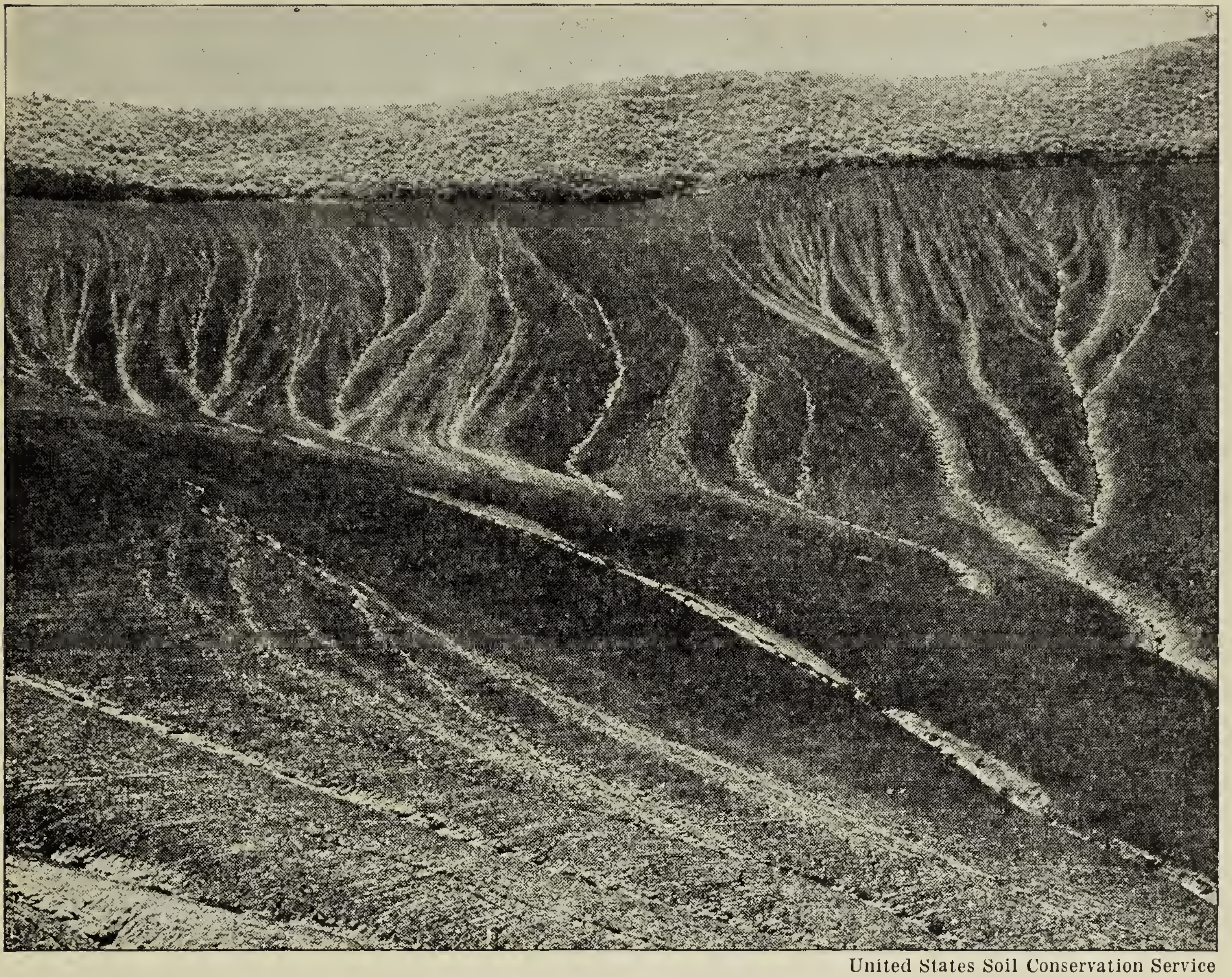

United States Coast and Geodetic Survey

Water erosion in Dinagat Island group, Philippine Islands

The Mississippi River carries a million tons of sand and silt to the Gulf of Mexico every twenty-four hours. In a year this mighty cargo of mud would load enough fifty-ton freight cars to make more than three freight trains, each reaching from New York City to San Francisco. Other large rivers, such as the Amazon, the Danube, the Nile, and the Yukon, together with thousands of smaller ones, are busily cutting away the land and carting it down to the sea. The great Colorado River, which is responsible for the Grand Canyon, has cut a gash over a mile deep, two hundred and fourteen miles long, and from eight to twelve miles wide as it plows through the rocks on its way to the Gulf of California. Physiographers tell us that the streams of North America by their action are plowing down the whole continent and leveling it off at the rate of one foot in nine thousand years.

Along the seashore, too, the booming waves pound against the faces of exposed cliffs and undercut them by grinding away their bases (see figure on page 526). In time of storm wave pressures of over two tons per square foot have been recorded. Finally, when the strain becomes too great, gravity pulls the overhanging tops down into the sea, where ultimately they are reduced to finer sediment by further action of the surging water.

Not only does running water carve away the land and transport its remains toward the ocean, but water that percolates down through the soil and rock is active in this respect, too. Owing to the pressure of the superimposed layers, which press the earth materials together and tightly close up the crevices and pores, relatively small amounts of water penetrate below the two-thousand-foot level. Above this level, however, vast quantities of ground water are present.

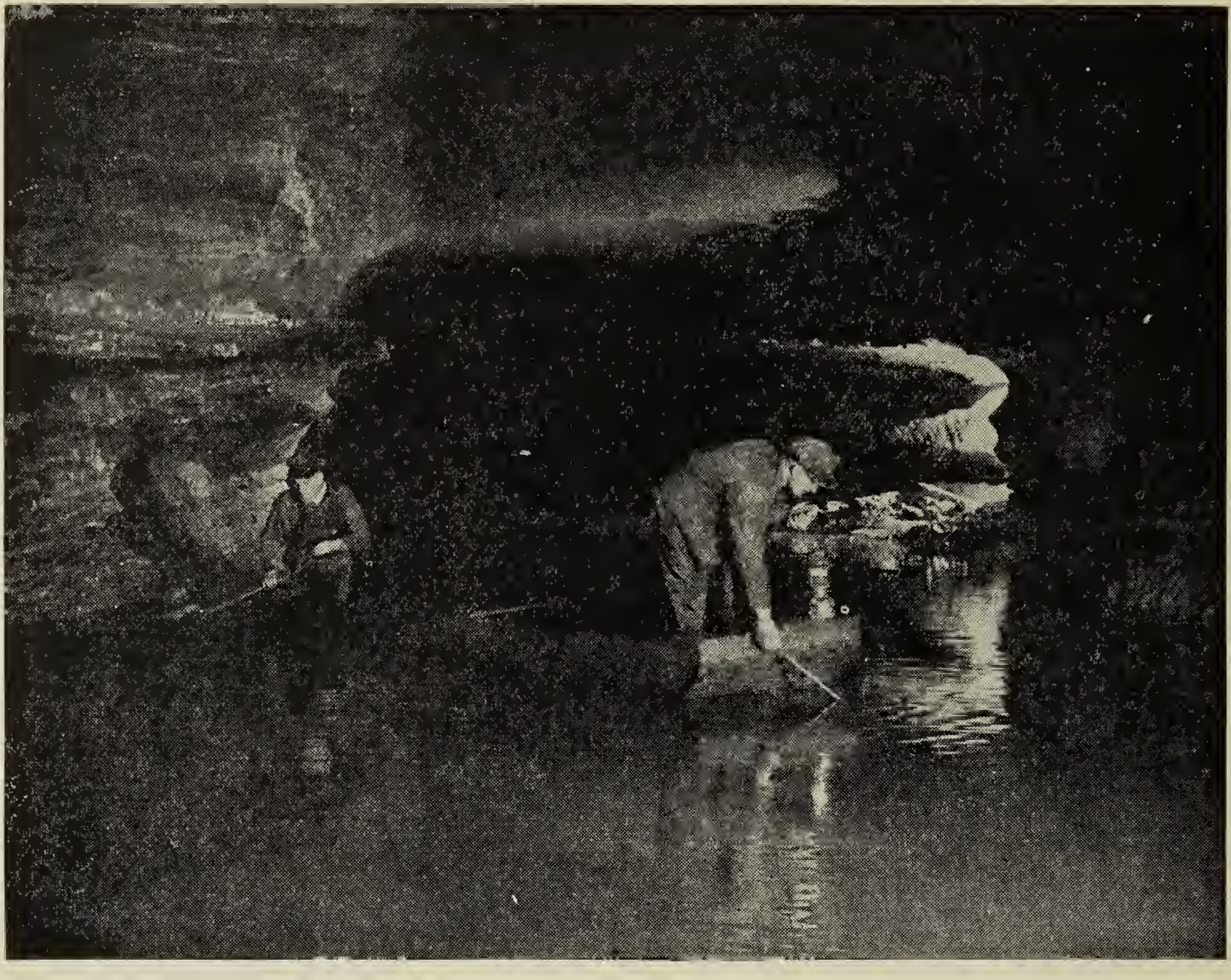


United States Soil Conservation Service

Sheet and rill erosion

The surface ground water gradually percolates downward to become a part of the general water table below. Oftentimes ground water, through its solvent action, excavates great subterranean caverns. The Carlsbad Caverns in New Mexico, the Cave of the Winds in South Dakota, and the Mammoth Cave in Kentucky are examples. It is estimated that the Mammoth Cave has a hundred and fifty miles of "streets," and the Carlsbad Caverns are so extensive that much of them has not yet been explored.

Much of the penetrating ground water comes to the surface again at levels lower than those where it entered the soil. Creeping along through the interstices of sand, gravel, and clay under the action of gravity, it finally encounters a more or less inclined impervious layer, along the top of which it flows to the surface, where it appears in the form of springs or seepage waters. Now becoming a part of creek and river, this emerging water carries its burden of dissolved mineral matter away from its place of original deposit. In this manner literally billions of tons of the more soluble portions of the earth's crust are moved seaward every year; in fact, about one-third as much material is carried in this way through stream courses as is transported by suspension.

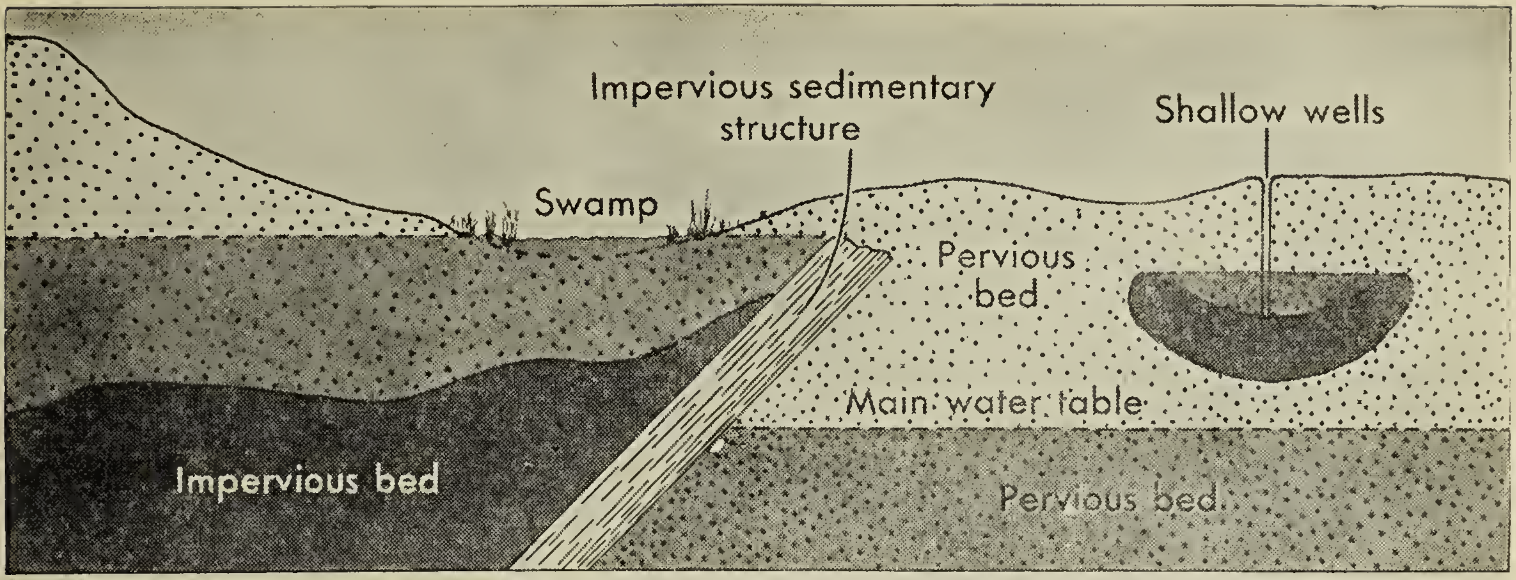


Echo River in Mammoth Cave

One of the most significant results of the geological effects of water is more subtle than most of the examples already cited. This effect takes place as either sheet or gully erosion on farm lands. Settlers in a new country pre-empt the virgin soil, cut off the brush and timber where they occur, and then plow up both this cleared land and the virgin sod. As long as the unmolested forces of nature are in possession of the land, the soil is fairly stable. It is held in place by the roots of grasses, trees, and shrubs. Moreover, it is protected from excessive washing by the cover of dead vegetable matter above. But when the soil is broken with the plow, the whole aspect with reference to erosion changes.

Hard showers and heavy rains occur as before, but now the soil is less firmly anchored than it was previously by the roots of the native vegetation. Moreover, the runoff is much heavier. Consequently excessive erosion begins. Governmental investigation carried on at Bethany, Missouri, with an average annual precipitation of 33.5 inches on an 8 per cent slope continuously cropped with corn, showed an annual loss of 67.4 tons of soil per acre.

About 75 per cent of the farm land of the United States is sloping land and



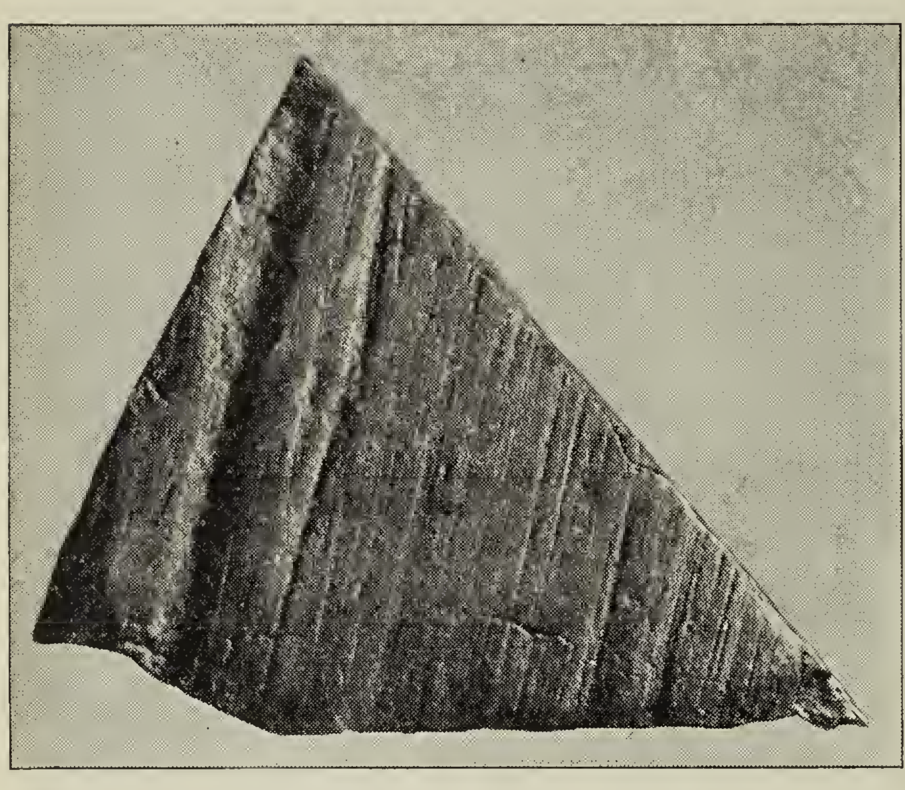
Effect of different strata on water table

A diagram to show how the perviousness and imperviousness of earth layers may cause different water levels

therefore subject to devastating erosion. The first seven or eight inches of topsoil is the really fertile part of our agricultural land, and it represents, as Dr. Bennett, director of the Soil Erosion Service, states, "the farmer's principal capital." Under present practices, the time required for the water completely to erode away this rich topsoil he estimates to be from three to sixty or seventy-five years, depending upon slope, rainfall, and cropping practices. On the particular Missouri slope mentioned, he concludes that the topsoil will be eroded away in about twenty years.

As a result of erosion, inland lakes and reservoirs silt rapidly, relatively speaking. All lakes of this character, regardless of their size or beauty, are doomed to be filled. This is another source of economic loss and aesthetic depreciation. In addition, the silting of stream reservoirs and river dams greatly increases the hazards from floods. Gibraltar Reservoir (two hundred square miles) near Santa Barbara, California, was completed in 1920. In it, silting for a fourteen-year period (1920–1934), owing largely to forest fires and mismanagement of the watershed, has gone on at the rate of 600 acre-feet per year. The Elephant Butte Reservoir on the Rio Grande in New Mexico, a very large and important one from the standpoint of irrigation, was estimated by its engineers at the time of construction to have a life expectancy of about two hundred and twenty years before silting would fill it. But at the present rate of deposit it is now estimated that in sixty years it will be rendered useless in times of protracted drought.

Glaciers as Eroding Agents. In elevated regions such as mountain ranges most of the precipitation through a large part of the year falls in the form of snow. As the snow accumulates, the melting point of the lower part of the drifts is reduced by pressure. Receiving heat from the sunlight and atmosphere and from that generated by pressure, the whole mass finally becomes congealed into a solid ice pack that tends to move under the action of gravity down mountainsides and canyons in the form of glaciers. Glaciers vary widely in depth and extent, and when they are large, they exert tremendous frictional pressure upon the rock surfaces over which they slide. Some of the larger ones are hundreds of feet deep. They may move a few inches or a few feet a day, depending upon the conditions. The Mer de Glace, one of the larger glaciers in Switzerland, moves approximately twenty-seven inches a day during the summer months and about half as fast during the winter season. Some of the large glaciers in Greenland are said to move sixty feet or more a day.


The grooves in this piece of stone were cut by glaciers

The weight of the ice alone would grind up the rock and make glaciers powerful eroding agents. Their effectiveness in this respect is greatly augmented, however, by the fact that the ice pack, pushing along in its course, picks up stones, pebbles, rocks, and boulders which become congealed into the mass at the bottom and move along with it. Boulders ranging from tiny ones to those weighing many tons are captured in this way. Now these rocky fragments, weighted down by the ice above, act like teeth in a giant rasp. Stones are crushed and broken, other huge boulders are dislodged from their places, and ledges that cannot be moved are scratched and abraded. Under the grinding action of the whole, thousands of tons of rock are thus reduced to fragmentary sizes and transported to the valleys below, where the melting ice drops them in the form of great windrows of mantle rock and debris known as moraines. At the head of the glaciers great amphitheater-like depressions are excavated, and sharp-edged, V-shaped, water-carved canyons have their sides smoothed up and their beds eroded out to a U-form in cross section.

Outside of Alaska, North America has no great glaciers at the present time. In prehistoric times glaciers a mile in depth flowed over two million square

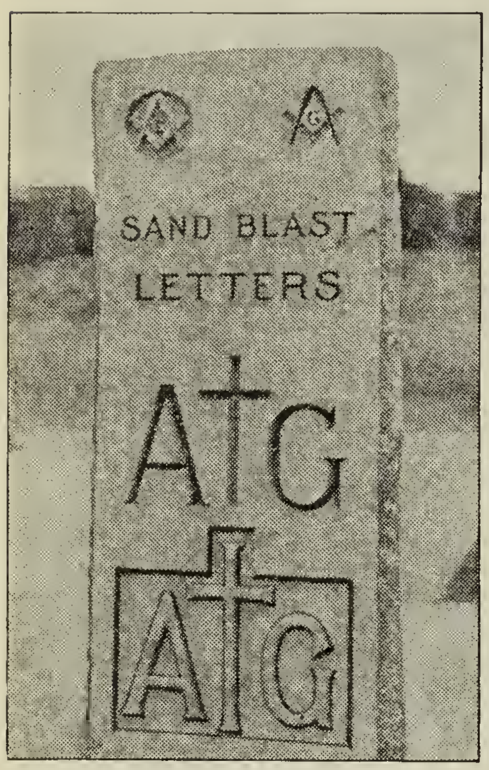
United States Geological Survey

A glacial moraine, more clearly seen at upper right hand

miles of Europe. More than four million square miles of North America were buried deep under glacial ice, the flow passing over the tops of such mountains as the Adirondacks in New York and rounding off their tops as if a gigantic float had passed over them. During the past million years it is estimated that at least one fifth of the total land area of the earth has been covered with ice. When these ice sheets melted, they deposited in some places soil-making materials several hundred feet deep. In Ohio, which is near the southern border of the great glacial area in the United States, an examination of about 2800 oil-well cores shows a deposit ranging from about 20 feet on the hills to as deep as 763 feet in a valley south of Cleveland.

Some of the most fertile agricultural soil on the continent, that of the north-central states, is found on the site of these deposits. In these regions the principal material cut out by the eroding water and transported down the Mississippi Valley for the past thousand years or more is this glacial drift.

Wind as an Eroding Agent. Wind is another very important eroding agent. Although air has a density of but one eight-hundredth that of water, when it moves at a high rate of speed it becomes a surprisingly effective eroding and transporting force. The wind, picking up small pieces of sand and dust, grinds them together and drives them against rocks and boulders with great abrasive power. The effect of such action may readily be seen by watching the operation of the sandblast, a device now widely used by contractors to restore the outside appearance of dingy, smoke-begrimed brick or stone buildings.



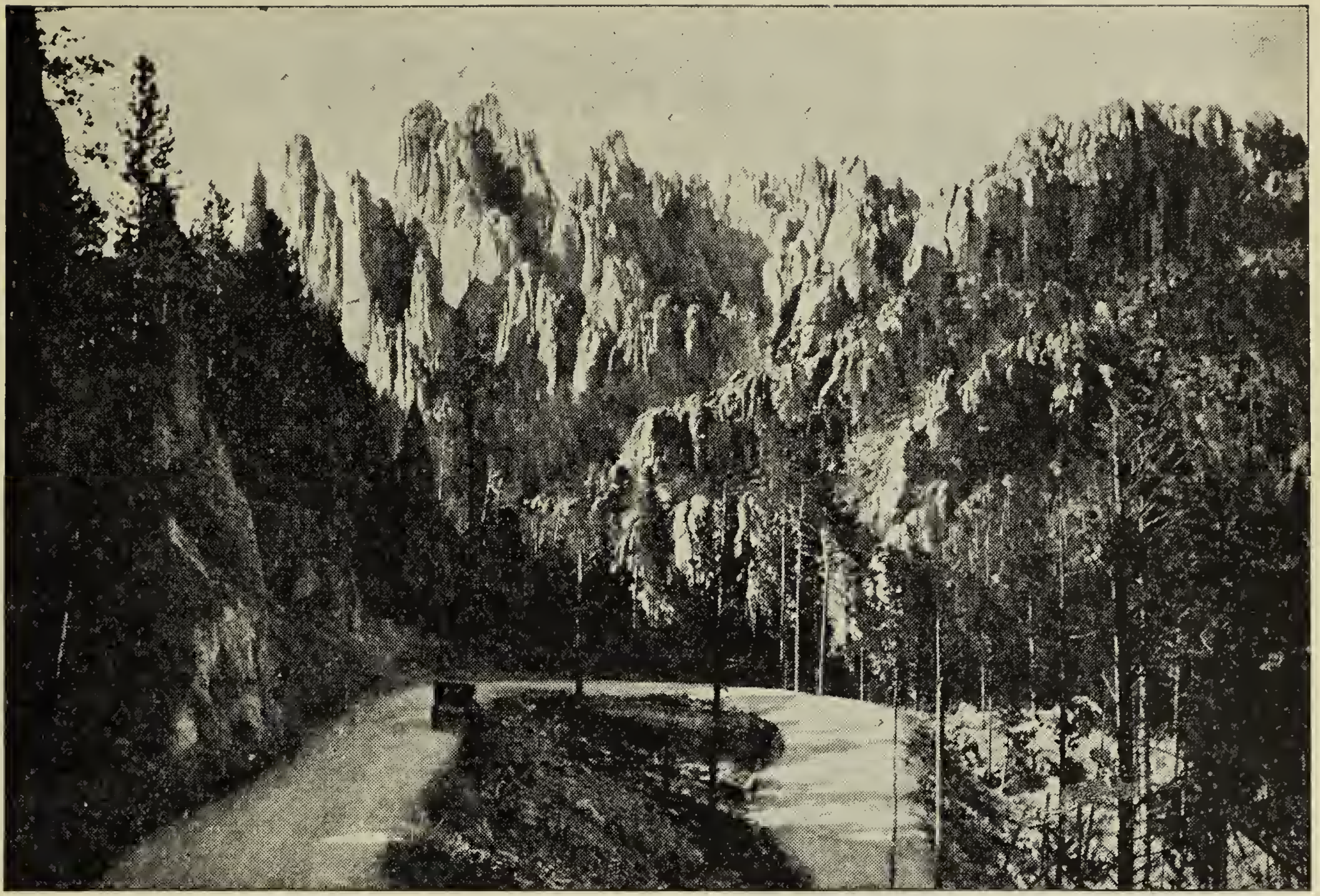
Sand as an erosion agent

The letters in this granite slab were cut with a sand blast

The action of wind as an eroding agent may best be seen in the region of sandy plains and deserts, along the sandy banks of streams, and up and down the seacoasts. Sometimes its action is rapid and sometimes slow, depending on the resistance of the abraded materials, the amount of sand carried, and the velocity of the wind. Along seashores windowpanes of houses may have their surfaces seriously impaired in a very few days by the cutting action of the sand grains. Indeed, under extreme conditions, the panes may be completely penetrated within two or three months. People living in sandy regions frequently are compelled to buy new windshields for their automobiles because the eroding, scratching effects of the wind impair the transparency of the glass.

As wind erosion goes on year after year, naturally the softer parts of the exposed rock surfaces are cut out and carried away first, leaving the more resistant and slowly wearing parts behind. The result is a great variety of residual rock forms, some of which are grotesque in appearance, while others may be very beautiful. The peculiar mushroom formations found in the Bad Lands of South Dakota and Nebraska, although chiefly formed by water erosion, have been finished off by wind erosion. The magnificent, highly colored spirelike structures towering heavenward in the Garden of the Gods at Colorado Springs, Colorado, are largely the product of wind abrasion and transportation.

As the eroded material is loosened by the wind, it, together with other dust and sand particles caught up from the surface, is carried across the country in great clouds in time of storm. A dust storm in February, 1937, picked up fine soil in the region of Dalhart, Texas, and is believed to have carried it far into Canada. Samples collected five hundred miles northeast at Clarinda, Iowa, show the dust to have come from the Texas plains. In the previous year the United States Bureau of Chemistry and Soils estimated, from samples of dust collected, that a deposit of ten tons per square mile at Saint Johnsbury, Vermont, blew in from the plains region west of the Missouri River.

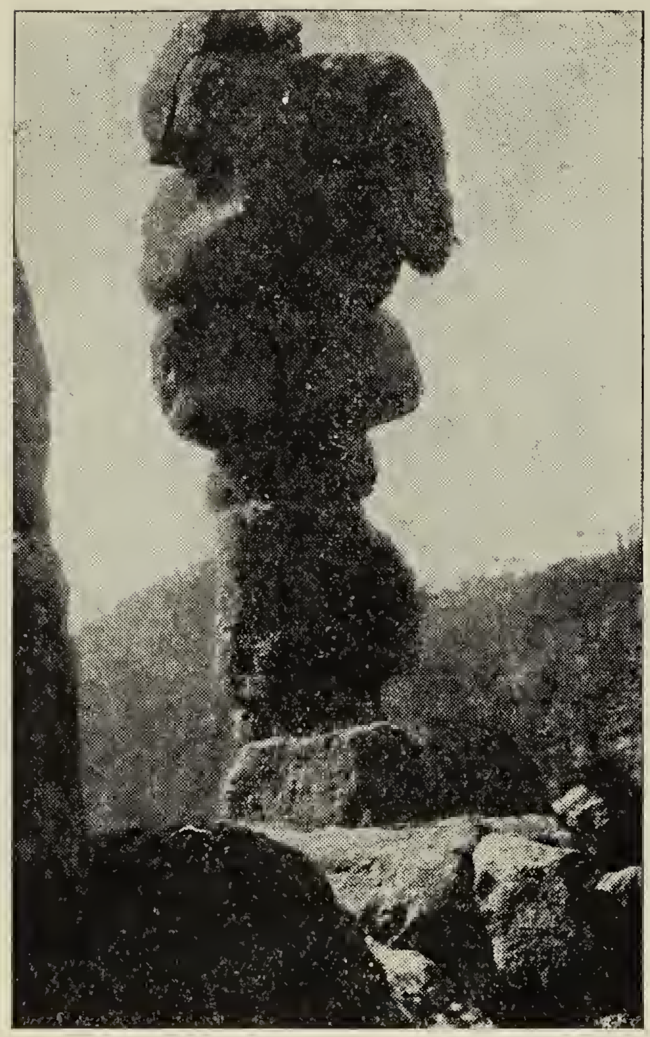


Black Hills Studio

Spires on Needles Highway, the result of wind erosion

A dust storm in the Middle West

When the velocity of dust-carrying winds falls, it permits the suspended load to settle slowly out of the air. Rains and snows are even more effective as clearing agents. Normally the rate of dust deposit in depth from this source is not rapid. But during certain periods the amount of soil deposited by the winds in some regions is surprising. Ancient cities were partly covered by such a mantle, and parts of the Mississippi Valley, the Palouse hills of eastern Washington, the plains of Germany, and the interior of China have been buried in this way. Soil so deposited is known as *loess.* The deposits range in thickness from a few feet to at least a hundred feet and in time may form a very productive subsoil.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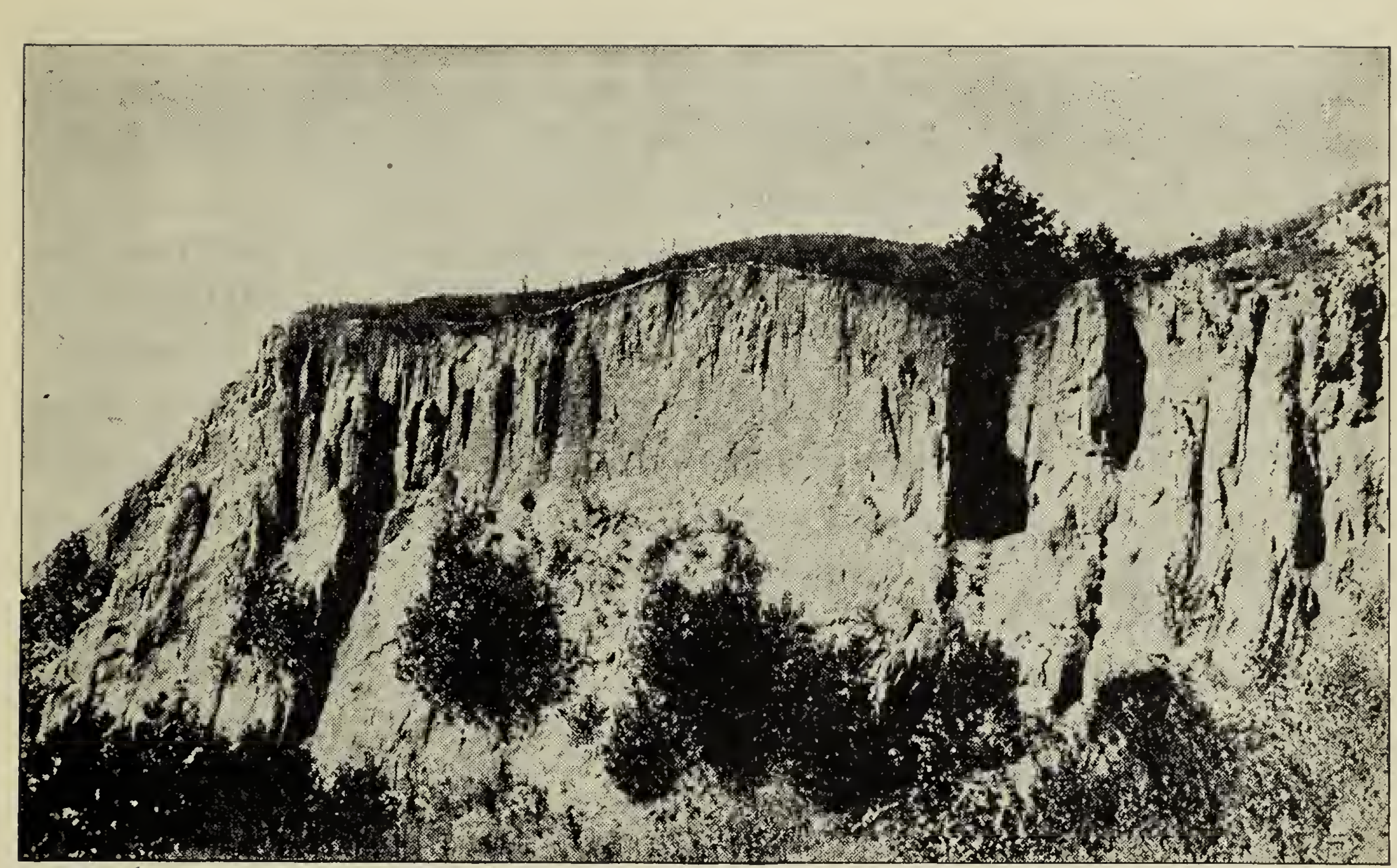
A balanced rock formed by wind erosion

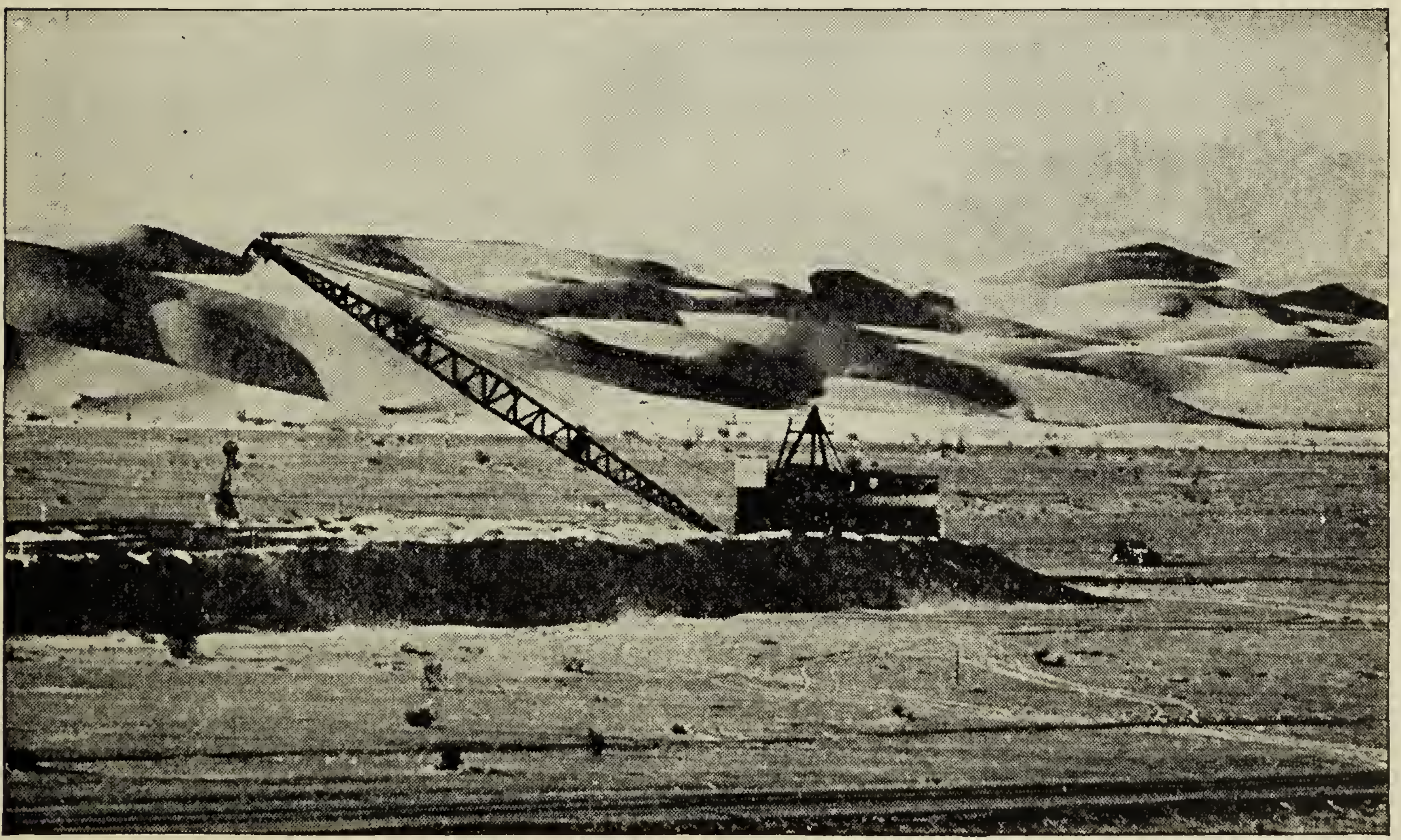
In some places, as on the southern shore of Lake Michigan and the sandy areas of Nebraska, Kansas, Oklahoma, and the Yuma Desert in southern California, the winds of the ages have piled up great sand dunes that go creeping along engulfing and destroying every object which happens to be in their path. Houses, trees, and, indeed, whole forests are sometimes overwhelmed, passed over, and finally left in the rear as devastated ruins.

Weathering and Erosion Tend to Level Off the Surface of the Earth. The forces of disintegration, decomposition, erosion, and transportation are many, far-reaching, and complicated in their interaction. They go hand in hand, all acting simultaneously and each making it easier for the others to exert their influence. Except in special cases, they apparently do their work slowly. Yet they go on hour after hour, day after day, century after century, and in the end tremendous changes are accomplished—changes that affect the whole earth's exterior. Hills and mountains are torn down, and valleys and oceans adjacent to land are filled in. The action of these forces is to cut down the whole continental areas gradually and to cart the resulting debris off to be dumped, ultimately, into the sea. The average elevation of the North American continent has been estimated at not far from two thousand feet. Assuming that its height is lowered by the forces of erosion one foot every nine thousand years, then in eighteen million years, if erosion continued at the



Alden from United States Geological Survey

Exposure of fifty to sixty feet of loess soil



United States Bureau of Reclamation

The hills in the background are wind-borne sand

These sand dunes are more than ten miles wide present rate, its whole area would be reduced to the level of the sea. Actually, however, it would take much longer for the forces of nature to accomplish this feat, because, as the continental gradient was reduced, the streams would slow up and the rate of erosion would be greatly diminished.

Nevertheless, if no compensatory movements in the earth's crust took place to maintain the land elevations, all continents would proceed toward this monotonous end. At length either they would be reduced to the condition of low, humid, stagnant swamps, or the water would close in over them and they would form the bottoms of shallow seas. Probably the latter alternative would take place. Life possibly would be reduced to aquatic forms, and the final page of human history would be written.

Fortunately, however, the elevating forces of nature are at work to balance the eroding factors and to keep the whole earth's surface in its present varied condition. In the succeeding chapter we shall see what these forces are and how their work is accomplished.

Questions for Study

1. In what ways has man's increased knowledge of the changing character of the earth's outer crust enabled him to understand his environment better?
2. How may igneous rock differ from sedimentary rock?
3. What theory seems to account for the preponderance of granites in the land areas of the earth's surface?
4. How are metamorphic rocks believed to have been formed?
5. What are some metamorphic rocks that are of great economic importance?
6. How may the black shales eventually become of vast economic importance to man?
7. In what ways do the fossil-bearing rocks enable man to make inferences concerning the past history of the earth?
8. How do the agents of weathering affect the earth's surface?
9. What are the important agents of erosion?
10. What concrete evidences have you seen of the eroding effect of water?
11. In what sense may the Grand Canyon of the Colorado River be said to be a textbook of earth history?
12. In what ways is the underground water table of great value to man?
13. What are some of the ways in which man's activities have tended to unbalance the forces and conditions of nature and accelerate erosion?
14. How can you explain the fact that many of the world's best farming regions are gradually "wearing out"?

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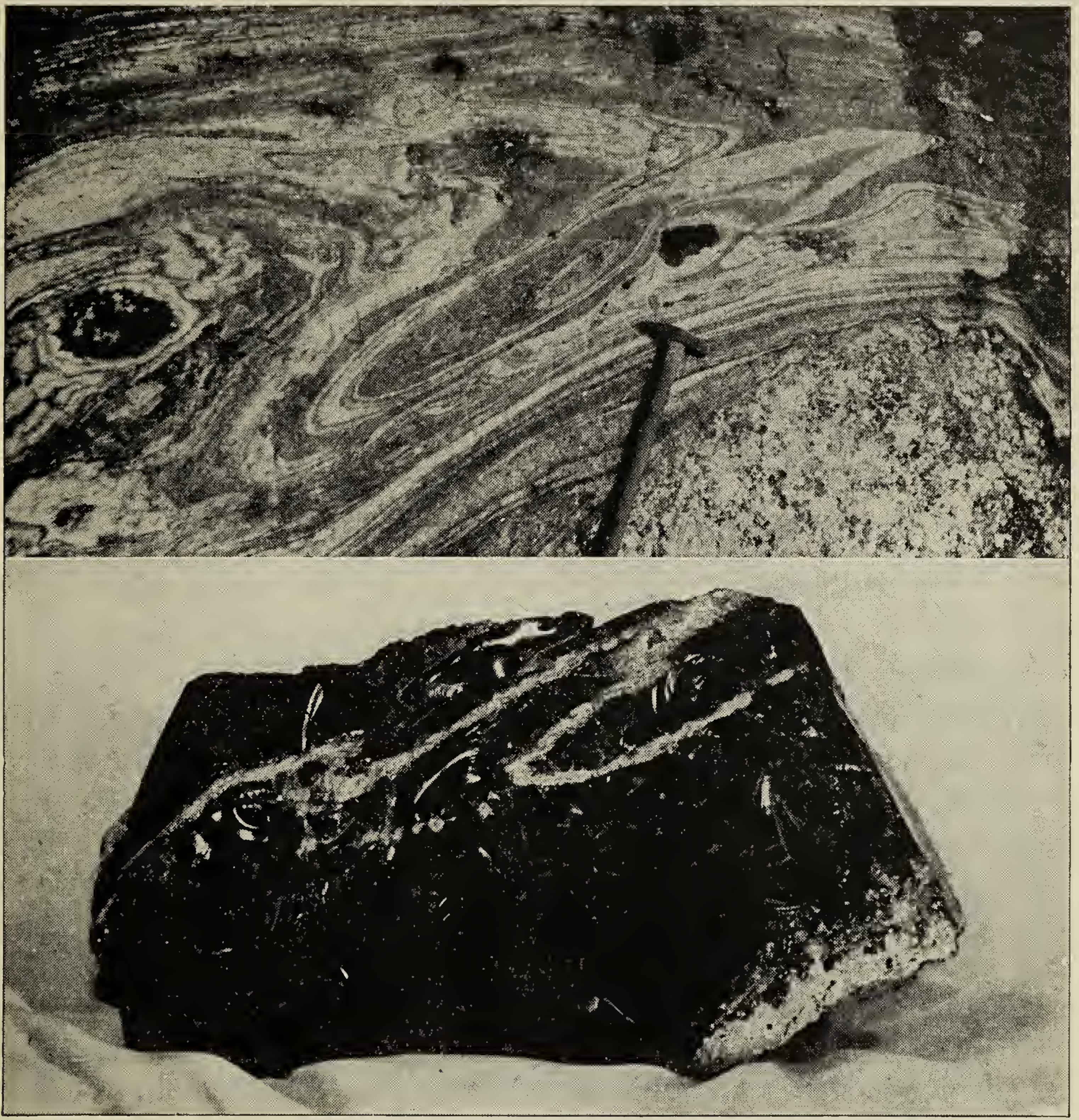
CHAPTER TWENTY-NINE

Aggrading Factors Tend to Compensate Eroding Factors

The Interior of the Earth Is Believed to Be Very Hot and to Manifest the Quality of "Flowage." From our experience with extremely limited portions of the exterior of the earth we are likely to draw very erroneous conclusions as to the conditions and processes taking place in its interior. Below the surface it seems cold, perfectly inert, and immovable. Appearances, however, are deceptive. Careful measurements and computations indicate that the earth, instead of getting progressively colder from the surface toward the center, actually becomes enormously hotter as great depths are reached. It is true that the surface two or three feet of soil in temperate climates is much warmer during the summer time than the soil a few feet deeper. This is due wholly to the heating effect of the sun as it is conducted downward. Below this level, conditions change and the temperature constantly increases at greater depths. It has been found in deep wells and mine shafts that on an average the rise is about 1° F for every 60 or 65 feet of depth.

An oil well recently bored on the plains of eastern Colorado to a depth of 6652 feet had a temperature of 194° F at the bottom. This temperature, it is well to remember, might have been influenced by local conditions; but doubtless part, if not all, of the increase in temperature with depth arose from the effects of the layers above. From these statements, then, it is obvious that the deep interior of the earth must reach a temperature of thousands of degrees.

This rise in temperature is believed to be caused chiefly by the work of compression produced by the weight of the superimposed layers. So rapidly does pressure mount that at a depth of a thousand miles it is estimated to be ten million pounds per square inch. At the center of the earth it is believed to reach the enormous figure of from forty-five million to fifty million pounds per square inch. It is evident that the compression due to this tremendous pressure would result in very high temperatures; in fact, it was reasoning from this point of view that led the early geologists to believe the center of the earth to be a molten mass. It is probable too that atomic energy from radioactive elements has supplemented the heat developed by pressure and contraction. Apparently there is no question in the minds of geologists now that the temperature is sufficiently high in the deep interior of the earth to fuse any sub-

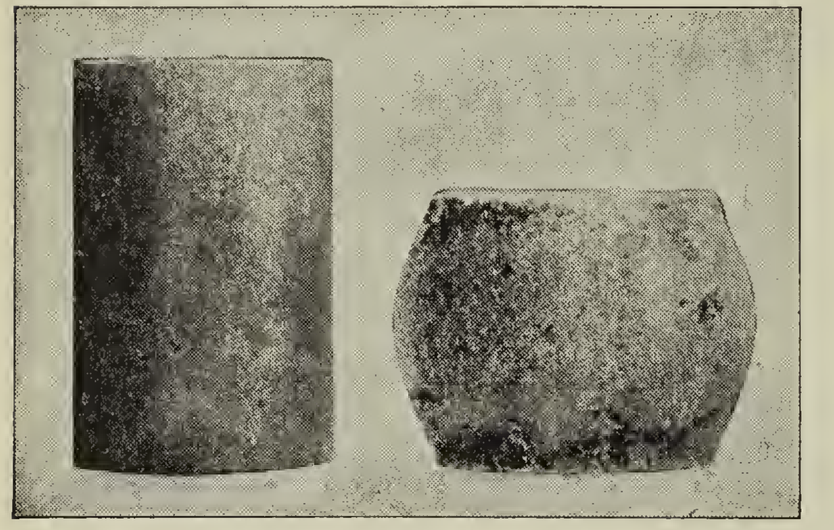


Geological Survey of Canada (upper photograph)

Flowage formation in squeezed limestone (above) and in basalt (below)

stance known. This same pressure, however, is the very agent that prevents the molten state. By it the molecules and their components are believed to be forced so close together as largely to overcome the inelastic properties ordinarily found in molten materials and cause them to take on the characteristics of rigidity found in solid substances.

Under pressure, ordinarily, molecular relations are modified and attraction tends to be overcome. When subjected to the pressure of heavy buildings some geological substances, such as shale, lose their rigidity and "flow." For this reason shale is unfitted as a bedrock to support massive architectural structures. All rock under sufficient differential stress tends, it is believed, to take on this "flowing" characteristic. The same kind of rock may vary widely in this respect. The range for sandstones, as shown by experiments, runs from 2000 to 17,000 pounds per square inch; for granite it extends from 20,000 to 38,000 pounds. Just as soon as a depth is reached where the pressure is sufficient, "flowage" begins to manifest itself. Down to a depth variously estimated at from seven to eleven miles a heterogeneous condition is found. The earth materials vary from the outer layers of mud that flow easily under the pull of gravity, through the stiffer, more viscid rocks that flow under pressure, to rocks that are still rigid and unyielding. When under excessive strain, these unyielding rocks do not flow, but often break and fracture. Hence this outer zone of ten or eleven miles is called the zone of "fracture" and "flowage."



Change in shape of a marble block due to flowage produced by pressure applied in the laboratory[1]

Below ten or eleven miles the combined heat and pressure are so great that all rocks probably move by flowage. However, the flowage under these internal conditions is not like that of a liquid. It is slow and creeping and takes place possibly by minute fractures and gliding planes, and by shearing and recrystallization. Its behavior is believed to be similar to that of ice moving in a glacier.

Some geologists explain the different densities of the earth materials from center to circumference on the basis of flowage effects. The movement would be extremely slow; but in the one or two billions of years that the earth is believed to have existed, great changes could have taken place. Under the constant pull of gravity the heavier iron and nickel ores, with a pace almost infinitely slow, would gradually creep to the lower levels, with the successively lighter materials arranged in a series above the central core, just as they are now believed to be. It must be remembered, however, that the flowage hypothesis is not necessarily in conflict with the elastic condition now believed to prevail deep within the earth. The elastic state is the effect of the tremendous pressure that must exist there. It is quite possible that if the weight of the superimposed layers of earth could be suddenly removed, the central part would explode with violent force. The compressed molecules rushing apart would produce this effect, just as some of the water in a steam boiler instantly vaporizes to produce part of the explosive force whenever the boiler explodes.

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[1] From *Structural Geology*, by C. K. Leith. By permission of Henry Holt and Company.

Erosion Tends to Distribute Weight and Pressure Unevenly over the Earth's Surface. We have previously emphasized that an astonishing amount of material is constantly being carried away from the land and deposited as silt in the sea. The million tons daily carried by the Mississippi River would cover a square mile to a depth of two hundred and sixty-eight feet every year. What this would mean in terms of total weight and exerted pressure may be computed but scarcely comprehended. Yet it is perfectly evident that the area occupied by the "Father of Waters" and its tributaries has been lightened by that same weight, and that the pressure added to the bed of the shallow water adjacent to the river's mouth has been increased by an equal amount.

A similar result has been produced by the Colorado River. Deposit of water-borne silt is believed to have advanced its mouth from the vicinity of Yuma, Arizona, to its present site, a distance of about 100 miles. This eroding and transporting process going on year after year, century after century, all over the land areas of the globe will produce a shifting of weight and pressure of almost incalculable proportions.

Earth chemists have discovered another set of factors that are materially contributing to these transitions of pressure areas. The weight, or specific gravity, of the chemical substances carried out of the soil and rock of the land and deposited in the ocean by the solvent action of water is appreciably greater than that of the insoluble, residual materials left behind. The principal solutes carried by the water are the heavier salts of sodium, potassium, iron, calcium, and magnesium; the insoluble, lighter materials left to form the soil are silica in the form of quartz and sand, and aluminum compounds, which go to make up the clayey constituents of the subsoil. Since it is estimated that about five billion tons of dissolved matter are carried to the sea every year, then it is evident that from this source too there must come a constant shifting of the burden placed upon different areas of the earth's crust.

The total effect of these agents of erosion and transportation, then, is to pile up material at certain points on the earth's crust and thus produce areas of unbalanced pressure. This unbalanced condition is believed to produce crustal readjustments which are far-reaching in their ultimate consequences.

Equal Vertical Sections of the Earth's Crust Weigh about the Same. Despite this constant tendency of the eroding forces of nature to distribute weight unevenly over the earth's surface, deep vertical sections of the earth's crust seem to have about the same mass. It would seem that with stupendous masses of the earth's crust being carted from the land areas and dumped into the seas, a condition would eventually result in which a vertical section of the ocean bed would be much heavier than an equal-sized section of the earth's crust beneath the land. Such, nevertheless, does not appear to be the case. The chief evidence against this supposition is presented by the swing of the pendulum.

One of the most exhaustive investigations with the pendulum which shed light on this whole problem was carried out a few years ago in a submarine by Dr. F. A. V. Meinesz of the Dutch Geodetic Commission. The apparatus he used consisted essentially of a set of three pendulums swung in a brass box about two and a half feet square. The box was mounted in a frame supported by a universal joint so that the whole would swing freely and take a perfectly vertical position regardless of the rolling of the undersea ship. A chronometer to time the instrument and an electrically driven photographic roll to record the pendulum swings completed the apparatus. To avoid the disturbing effect of the surface waves, observations were made at a depth of about one hundred and seventy-five feet. On this extensive voyage more than two hundred readings were taken.

It will be remembered that the oscillation of a pendulum is affected materially by the density of the mass attracting it and causing it to swing. The denser the mass, the faster the pendulum swings, and vice versa. Now, if a vertical section of the earth's crust were denser just out from a river's mouth where great quantities of relatively heavy sediment had been deposited, the difference would manifest itself in a faster pendulum-beat than would be given over a very deep part of the ocean bed where the crust is comparatively thinner. Meinesz, however, in general found no such differences. The time of pendulum-swing was practically the same in both places. By comparing these observations with others made over the land areas, even with those recorded on mountain ranges, the results agree. Whenever corrections for increased distance from the earth's center are made, the pendulum swings at the same rate. All of which goes to show that equal vertical sections of the earth's crust have practically the same mass when taken as a whole and that they consequently have the same measure of attraction for a swinging pendulum.

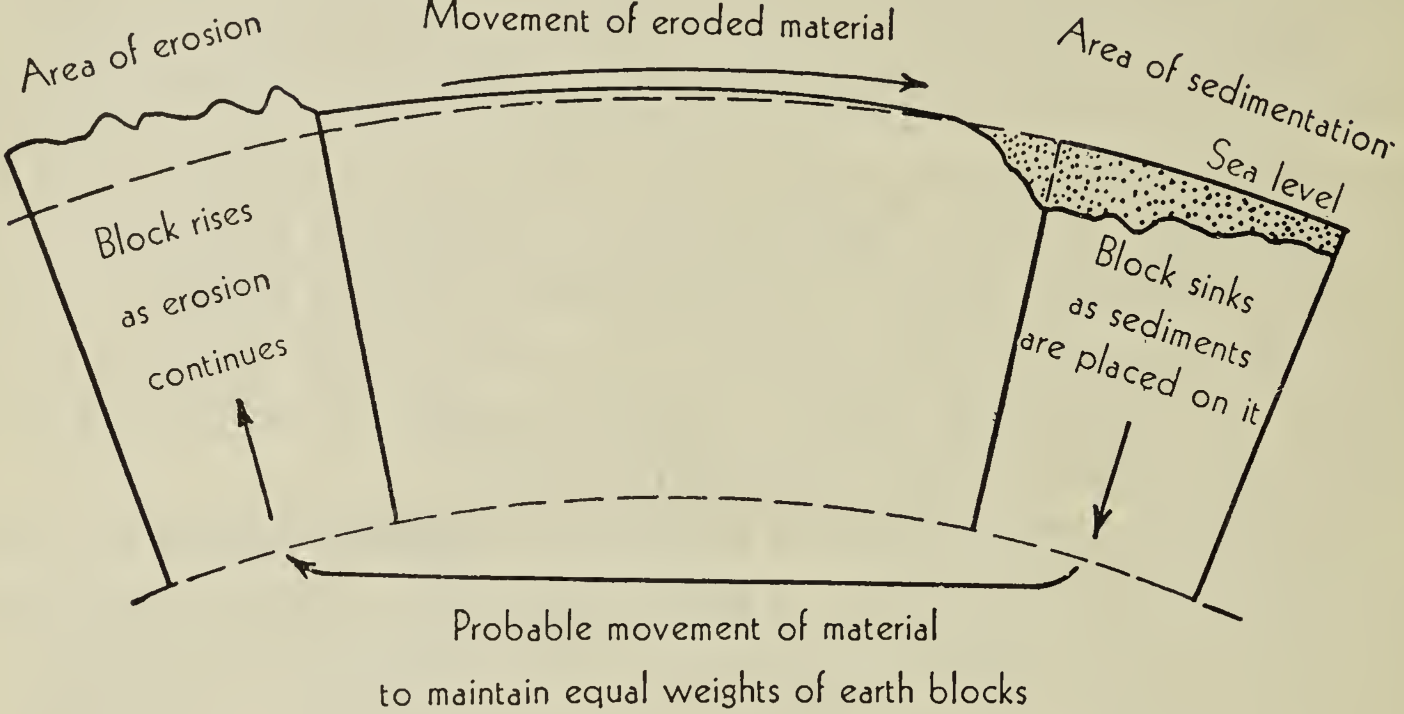
The reader will readily recognize, of course, that the earth's crust is not divided into sharply defined blocks or sections. The term *vertical sections*, as applied to the earth's crust, is relative and signifies only that the centers of two more or less adjacent sections of the earth's crust are, gravitationally speaking, out of equilibrium. There is no sharp line of demarcation between these blocks. Indeed, one gradually merges into the other.

Now it is evident that if one were to take successively equal lengths of an earthen core, such as is removed in drilling an oil well, these sections would not all be of the same density, neither would they weigh the same. But how is the difference in densities among the more superficial layers of the earth's crust to be harmonized with the testimony offered by the pendulum that all like vertical sections of the earth's interior from the surface downward have the same mass? This was a geological puzzle, indeed, and a very difficult one to answer. However, almost contemporaneously with the problem as it came into clearer perspective, the elements of an answer to the question presented themselves. The solution may be summed up under the single term *isostasy* (Greek *isos*, "equal," + *stasis*, "a standing still").

The Earth's Crust Is Believed to Be in a Condition of Isostasy. Isostasy is a comparatively new concept in geophysical science. Its main conception is that although the superficial strata of the earth's crust may vary among themselves as to density, and the weight of the vertical layers at one location for some distance down may be greater than the weight of the vertical layers at another location, yet, as depth is increased, these differences in mass tend to disappear. Finally, owing largely to the enormous pressures exerted, a depth is reached at which the inequalities wholly disappear, and the entire spherical zone of the earth's interior at that level becomes homogeneous as to density. In other words, although the superficial layers of the Rocky Mountain region and the strata underlying the neighboring Pacific Ocean may differ as to density, yet a depth under each is finally attained at which the density becomes equalized. The mountainous strata are less dense; but they are piled up higher, and this compensates in weight for the thinner, heavier strata that form the floor of the ocean bed.

To use a figure that Dr. Meinesz has employed in explaining the theory, if the surface of the globe down to the bottom of the crust (which has been estimated to be sixty miles) were cut up into squares a hundred miles each way, somewhat after the fashion of huge watermelon plugs, then all the geological "plugs" so formed should weigh about the same. This would be true, even though the "plugs" taken from the Himalaya mountain region would be approximately ten miles thicker than those taken from the deepest troughs found in the Pacific Ocean.

Under the tremendous pressures exerted at a depth of between 40 and 80 miles,—as a mean, let us say 60 miles,—conditions of *ready* flowage in the earth's materials would prevail. This, it must again be said, does not mean that the rocks at this depth are molten. Rather the immense pressure exerted causes the molecules to slip past and around one another, so that the whole mass becomes somewhat plastic and, under prolonged stress, flows. Consequently, as the heavily laden sea bottoms gradually sink under their growing burdens of superimposed sediment, the increased pressure set up is transmitted about equally in all directions. Wherever this augmented pressure happens to act upon strata of lighter material above its zone of action, the force tends to push these strata outward and, when transmitted to the earth's surface, the effects appear as a land elevation.


Area of erosion
Movement of eroded material
Area of sedimentation
Sea level
Block rises as erosion continues
Block sinks as sediments are placed on it
Probable movement of material to maintain equal weights of earth blocks

A diagram to explain the supposed mechanism by which balance is restored when load is shifted on the surface by erosion

The eroded area at the left continually loses weight, which is added to the low area at the right. In time this loaded part of the crust sinks and forces deep-seated rock to move horizontally by slow plastic flowage. This material moves underneath the eroded block, which rises to a position of proper balance. The plains area across which eroded sediments are transported suffers neither depression nor uplift. This diagram is highly artificial, since there are probably no definite freely moving blocks in the lithosphere[1]

Here, then, arises one of the major compensatory movements in nature that prevent the earth's surface from being plowed down to a dead level. Other forces may be involved, too, but these isostatic movements are an important reason, it is believed, why the continents are able to hold their own against the eroding, disfiguring ravages of time. It remains yet to be satisfactorily explained why these great regions of subsidence have sometimes shifted position in geological history; but some headway is being made now on that aspect of the theory by the geophysicists, and if the isostasy hypothesis proves to be true all these difficult points will doubtless be cleared up in time.

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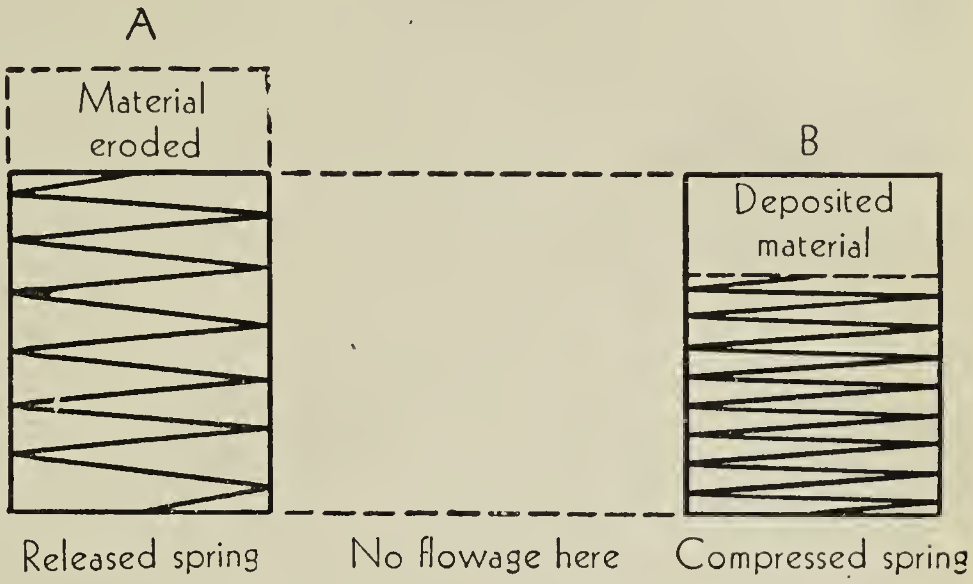
[1] Modified from W. Bowie. From *Textbook of Physical Geology*, by Longwell, Knopf, and Flint. By permission of John Wiley & Sons, Inc.

There are other explanations for these readjustments which do not recognize flowage. One of them may be called the *elastic-earth theory.* From this point of view all sections of the earth's crust, some distance down, because of the superimposed layers, may be considered to be in a state of compression-tension equilibrium, just as a coiled spring may be under compression tension. If the surface is heavily eroded at one point, the crust grows less massive over that area, and the elasticity of the deeper layers of the earth's crust pushes that particular earth block up. At the point of deposit, on the other hand, weight is added, and the "earth spring" tends to compress farther, so that the earth block at that point subsides. Such a view disregards the element of flowage, if, indeed, it does not deny it.



A diagram illustrating how, according to the elastic-earth theory, a rigid, yet elastic, earth body may respond to a removal of load (column *A*) and to a deposition of load (column *B*)

The elastic earth acts like a steel spring, and when the load is removed by erosion, the earth material tends to rise, as shown in column *A*. When the load is increased by deposit of material, the earth material is compressed, as in column *B*, and tends to sink. Flowage of rock from the base of *B* to the base of *A* is not necessary for adjustment[1]

Great Crustal Movements Appear to Be in Continuous Progress. On the assumption that the theory of isostasy is the most plausible one, geologists have been able to offer an explanation for many heretofore baffling movements in the earth's crust. For example, it has been known for many years that an elevation is taking place along the Canadian border in the region of the Great Lakes. This is known from the fact that fossil shells are found embedded in strata now raised above the water level. This movement is tilting these inland bodies of water in a direction from northeast to southwest. Up to the time of the opening of the Chicago Drainage Canal the subsidence at Chicago had been estimated to be about nine inches a century. On the northeastern shores of the lakes the old beach stands several hundred feet above the present water line. If this action continues unarrested, Lake

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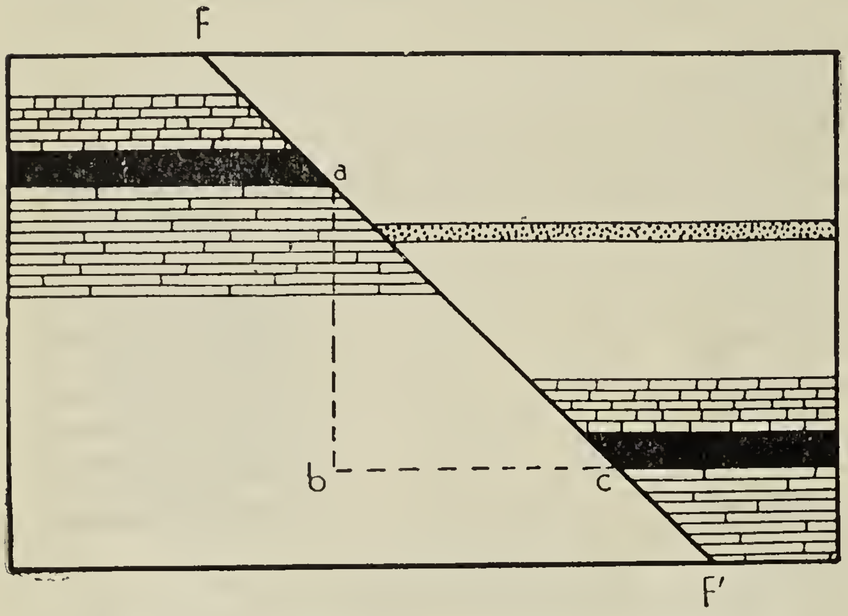
[1] Based on a discussion by Bailey Willis. From *Geology,* by Emmons, Thiel, Stauffer, and Allison. By permission of McGraw-Hill Book Company.

Michigan is on the way to emptying itself into the tributary waters of the Mississippi and will finally add its volume to the Gulf of Mexico. In the region of Lake Champlain and Montreal the present elevation is six or seven hundred feet above its former level; and a like movement is occurring in the Scandinavian peninsula. Parts of the New England coast are believed to have subsided in recent geological times, as has also the northern coast of France. These compensatory movements seem to be taking place at many other points on the earth. Darwin, during his voyage on the *Beagle*, found unmistakable evidence that the greater part of the southern portion of South America is rising and that this action is being balanced by a simultaneous subsidence of the Galápagos Islands, five hundred miles out in the Pacific.



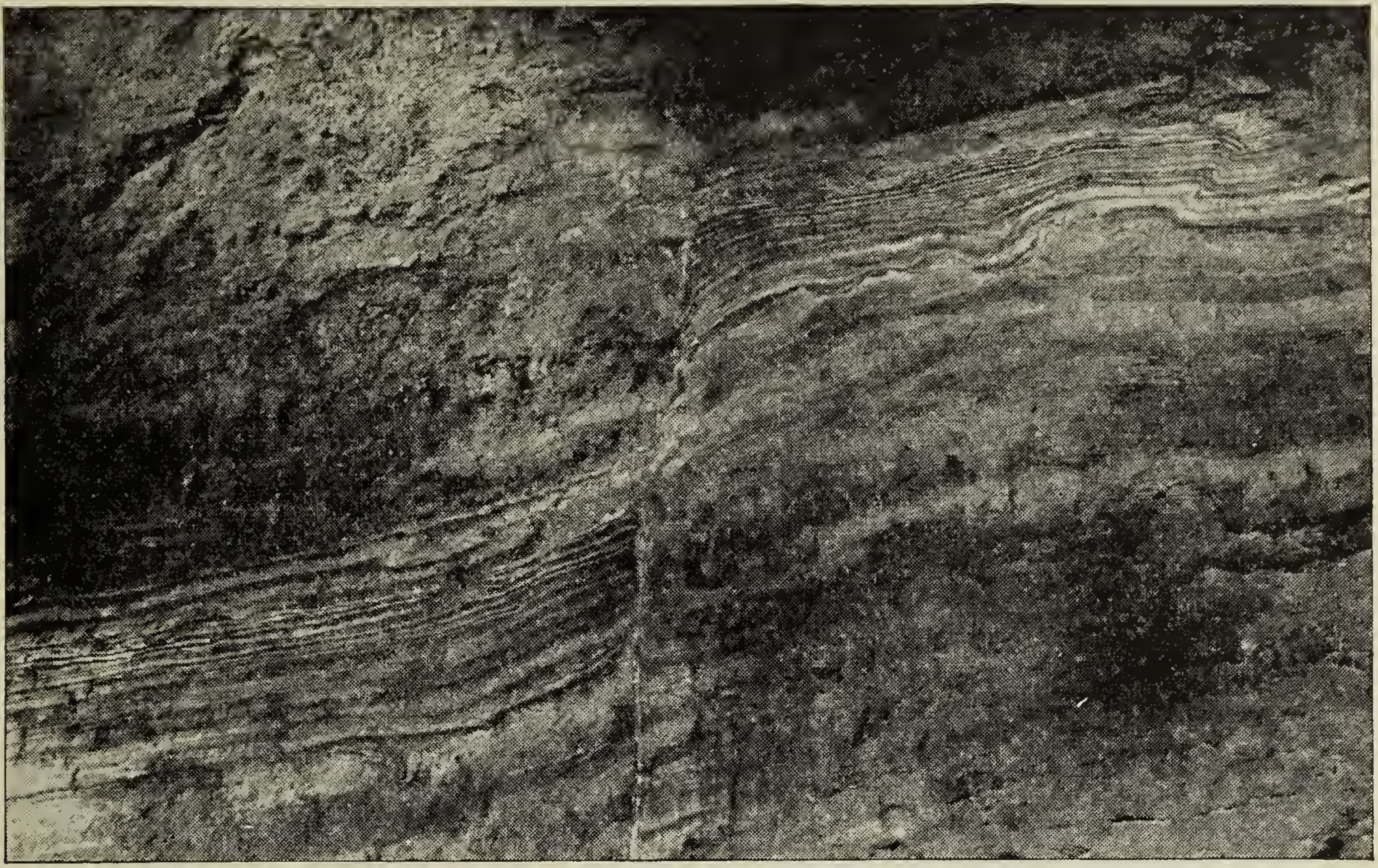
A diagram to illustrate a fault line along the line FF′

Note the vertical and horizontal shift of strata along the dotted lines *ab* and *bc*

Dr. William Beebe concluded, after careful investigation, that in the Bermuda islands a former area of five hundred and seventy-six square miles has been reduced through subsidence to a present area of twenty square miles. Dredging operations have revealed former sea beaches to be submerged to a depth of over one and one-half miles.

Earthquakes Are Caused by Readjustments in the Earth's Outer Crust. As we have found earlier in this chapter, the earth's crust down to a depth of ten or eleven miles constitutes what is known as the zone of fracture. Certain portions of this superficial "skin" may become, under the resident pressures, sufficiently plastic to flow. But some kinds of rock remain brittle under much higher pressures than others do. So, scattered through this, let us say, eleven-mile outer layer are some portions that remain hard and unyielding and, because of this condition, fracture when subjected to excessive strain. It should be kept in mind, too, that for many feet down from the surface all the rocks are subject to fracture because the pressure of the superimposed layers has not yet become sufficient to reduce them to a state of flowage.

Because of these conditions of fracture the extreme outer crust of the earth, relatively speaking, is intersected with a system of cracks and fissures which break it up into blocks of various sizes. Sometimes these cracks and fissures

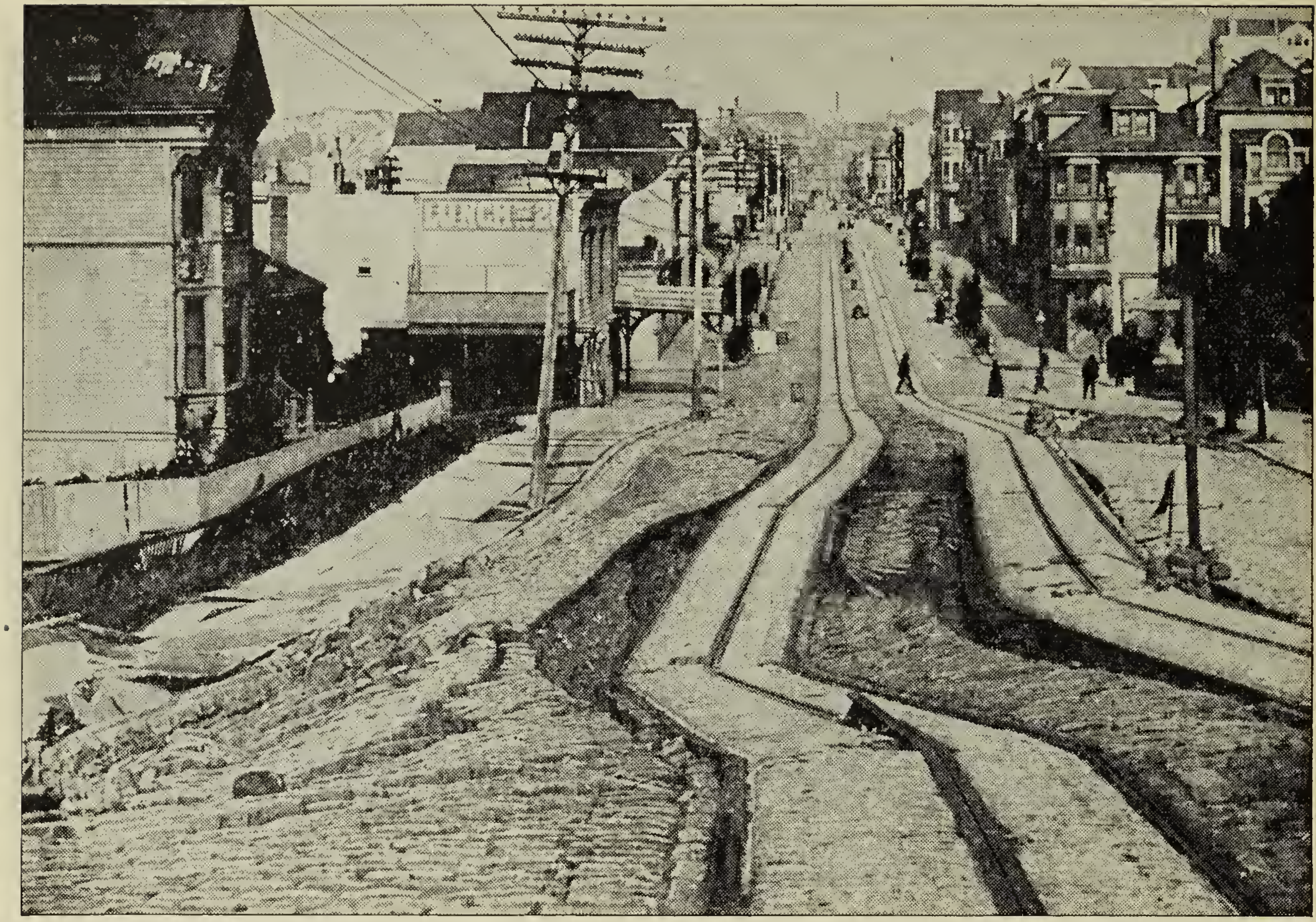


United States Geological Survey

A normal fault in sandy shale

are shallow and comparatively small; at other places they are deep and very large, involving the disturbance of thousands of cubic miles of rock and extending over the surface for hundreds of miles. They can easily be seen on the face of a rocky cliff, but out on the level they are usually obscured with sediment carried in by the trickling water. Sometimes the larger fissures penetrate to great depths, as may be seen in mine shafts.

It is the blocks formed by these larger intersecting fissures that are the chief actors when earthquakes occur. If a severe differential strain be brought to bear upon them by the development of a subterranean cavern, a magma intrusion, volcanic action, shrinkage of the earth due to radiation, isostatic readjustment, or other cause, they sometimes slip past one another, producing what is known as a "fault." It is this displacement that produces the earth tremor, or earthquake. The movement of the blocks along the fault may be either vertical or horizontal or, more often, a combination of both. Shimer tells us that in Yakutat Bay, off the coast of Alaska, a vertical fault occurred in September, 1899, in which one block had the forest on it killed by being submerged in the sea and in which the adjacent block was elevated, in one place, to a height of forty-seven feet. In the disastrous earthquake at San Francisco in 1906 the vertical displacement did not exceed from one to three feet, but the lateral thrust was as much as from eight to twenty feet. The ex-



Underwood & Underwood

This street railway was laterally displaced by an earthquake

tent of the horizontal movement was revealed by the lateral displacement of fences and railroad tracks. This fault is known as the San Andreas rift and may be traced by its peculiar surface expression from the southern part of the state six hundred miles to the northwest. The abrupt movements causing the quake of 1906 could be traced by the surface features along the rift for about two hundred and seventy miles.

The famous Bright Angel Trail at the south rim of the Grand Canyon follows the line of an old prehistoric fault in which the vertical displacement is estimated to have been one hundred feet. If all this displacement occurred at one time, it must have been accompanied by an enormous and terrifying quake. The more recent Kaibab Trail down to the Colorado follows another fault across the Redwall limestone strata.

The most violent series of earthquakes known to have occurred on the North American continent took place in the lower Mississippi Valley in December, 1811, and the early part of 1812. Almost two thousand distinct tremors were felt, and this whole section of the country was devastated. Boundaries, after the disaster, were so confused by the faulting that the government had to run surveys again for approximately a million acres of the most severely affected land. In at least one place, in Kentucky and Tennessee, the subsidence was so great as to produce Reelfoot Lake, twenty-five miles long. These geological disturbances are believed to have been caused as a result of the overburdening of that portion of the earth's crust by the vast quantities of sediment carried down by the Mississippi River. As the weight became too great, shifts had to be made to relieve the strain and restore the equilibrium.

Pavement crushed by shortening of the crust of the earth

Earthquakes, although lasting but a few seconds, may be very violent or so light as to be wholly imperceptible, depending on the nature and extent of the fault. In vertical slips the actual movement of the rocks at the point of origin (especially if this be relatively deep down in the earth's interior) may not be more than a few millimeters or centimeters at the most; yet the vibrations set up by the faulting travel through the elastic rocks out to the surface at a high rate of speed, where they may produce very destructive agitating and tossing effects. The results are much the same as those one would get if he erected a house of blocks on a table and then hit the underside of the table top a sharp blow with a hammer. Lateral thrusts result in greater displacement and, if violent, are very destructive.

The most tragic and disastrous earthquake of recent times occured in Japan in 1923. The cities of Yokohama and Tokyo, as well as buildings in the surrounding country, were almost completely destroyed. The razing action of the earth tremors, together with the effects of fire and the great wall of water that rolled in from the sea, resulted in the death of more than 140,000 persons and an estimated property loss of $3,000,000,000. Chile also suffered a catastrophic earthquake in the early part of 1939.

These severe quakes are terrifying. The earth, which we have come to

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Displaced by earthquake in Japan

regard as the most stable thing in the world, suddenly begins to shake and to form great cracks and fissures. The sides of cliffs and bluffs may slip away as landslides; where an impervious layer of clay covers a stratum of water-bearing sand, fountains fifteen or twenty feet high may gush forth from crevices; walls of buildings creak and fall; tall brick chimneys topple; bells ring; dishes crash from their cabinets; and pictures drop from the walls. Water pipes burst, and frequently fires from broken gas mains follow. The whole scene is most terrifying; no one knows which way to turn for safety.

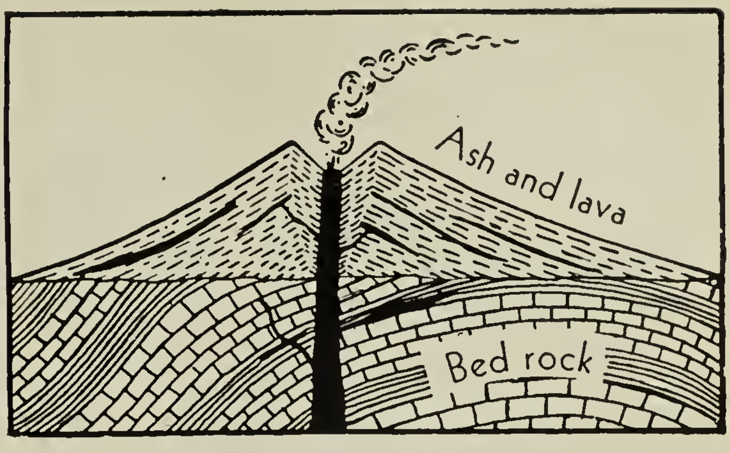
Earthquakes are surprisingly numerous. Dr. Bowie of the United States Geodetic Survey gave eight thousand as the annual number, of one magnitude or another, recorded by the seismographs stationed over the earth. Including the very light ones, imperceptible to most instruments, he estimated that there are several times eight thousand within a year. From this it may be seen just what a "shaky" place the earth is. Owing to a continuously acting and complicated set of forces, different parts of the earth seem to be quaking all the time.

Mountains Are Formed by Different Geological Agencies. Closely related to the subject of earthquakes is that of mountain-building. No discussion of the crustal movements of the earth, however brief, would be complete without giving some attention to the forces at work to produce these elevations and to the geological conditions out of which they arise.

There is no aspect of the earth's architecture which is more illuminating and at the same time more puzzling than its mountains. Mountains furnish

R. L. Campbell

Capulin Mountain, New Mexico, an accumulation mountain



A diagram to show the structure of an accumulation mountain[1]

the best evidences of great earth changes through sedimentation, subsidence, intrusion, thrusts, faulting, land elevation, and erosion that are available anywhere. Indeed, they present the chief clues which earth scientists have followed out in unraveling both the nature of the forces that have been active in fashioning the earth's crust and the far-reaching changes which these forces have produced. Volumes have been written on mountains, but we shall have to be content here to note three or four of the most important kinds of mountains, together with the forces that seem to have contributed most to their formation.

Volcanic Mountains. One of the most obvious causes of mountain-building is the accumulation of volcanic lava and dust. Great peaks are often produced by such accumulation. As the volcanic dust and lava are expelled, they either fall about the vent or run down, harden, and gradually build up a conelike structure of mountainous proportions. In extreme cases the amount of rock debris extruded is surprising. Tembòro, a giant volcano off the island of Java, is estimated to have blown out between twenty-eight and fifty cubic miles of material during its historic eruption of 1815. Katmai, an Alaskan volcano, erupted so much ash in 1912 that the country for a hundred miles around was in darkness for more than two days. The ash fell to a depth of six inches one hundred and sixty miles away.

Some of the most noted peaks in North America were built up largely by accumulative action about the mouths of volcanoes. Often volcanoes become active in mountains that had previously been formed by other agencies. In such cases both elevation and accumulation combine to form the peak, so that the material composing it is of mixed origin. Mt. Shasta, of composite origin but formed mainly by successive outflows of lava on other material, is 17 miles

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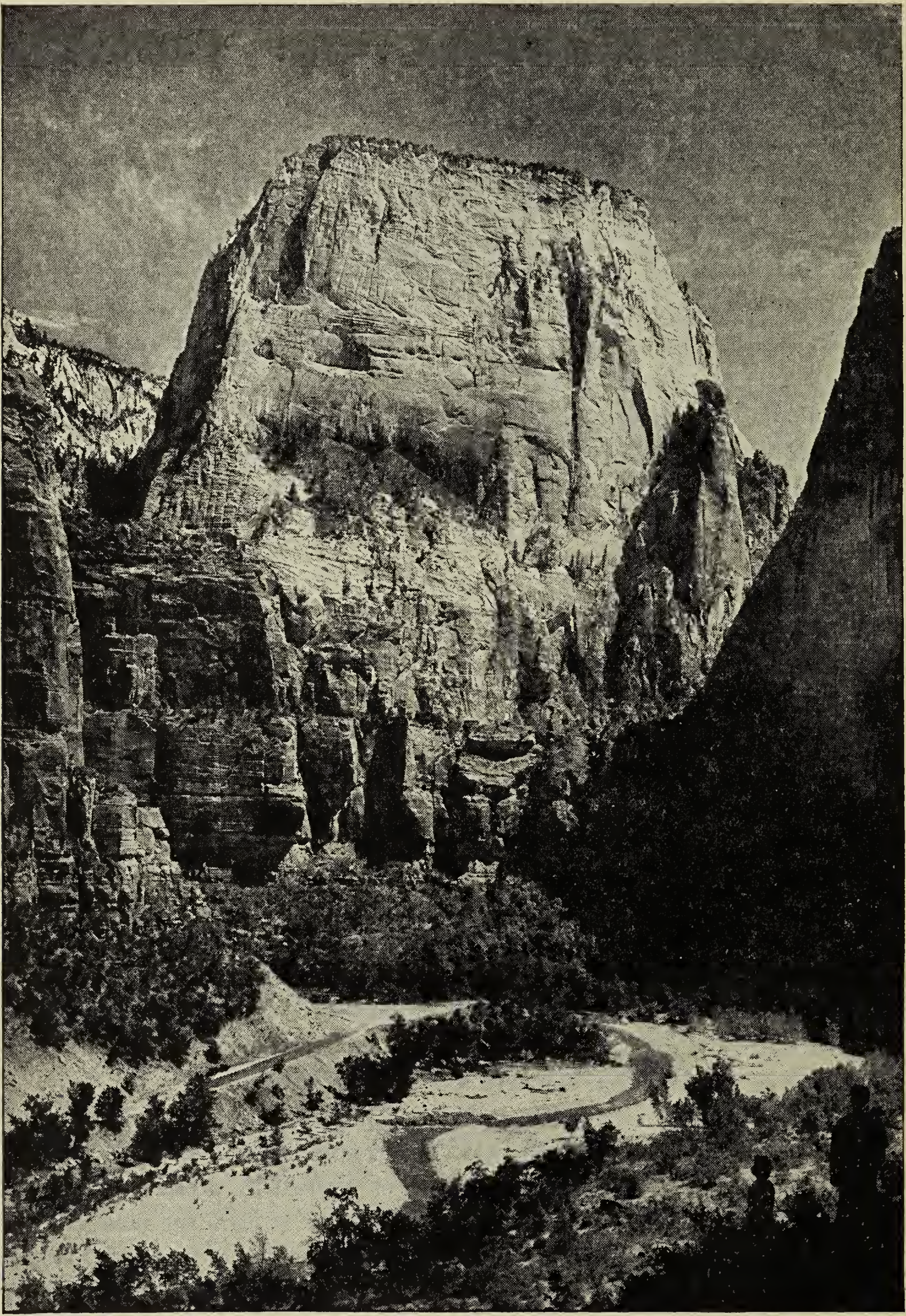
[1] From *Textbook of Geology*, Part I, *Physical Geology*, by Pirsson and Schuchert (third edition, revised under the editorship of Chester R. Longwell). By permission of John Wiley & Sons, Inc.



Union Pacific Railroad

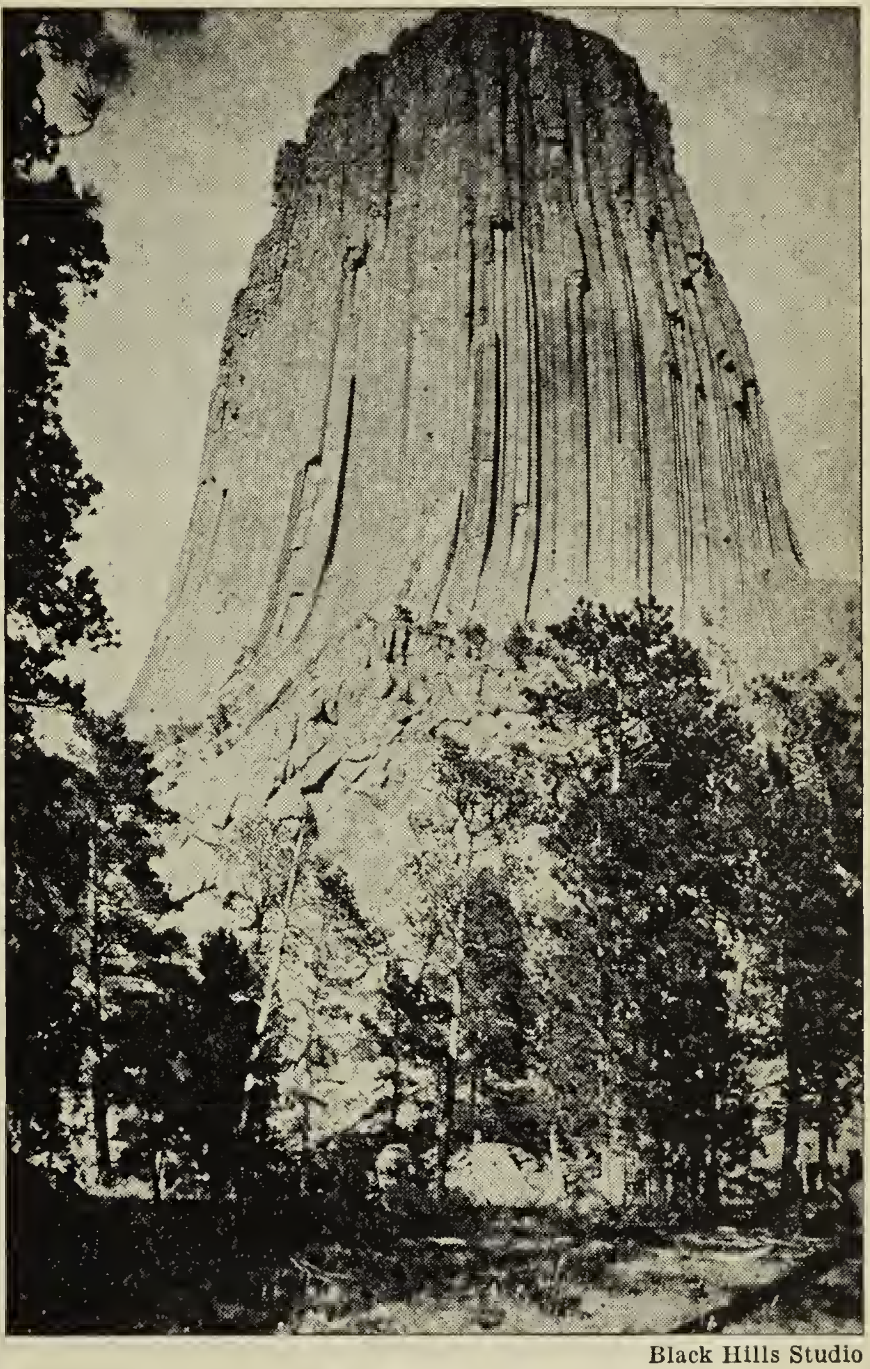
The Great White Throne, a residual mountain

In Zion National Park

in circumference at the base, and its cone is 5000 feet above the surrounding terrain. Its height above sea level is 14,161 feet. Mt. Rainier (see page 498), another peak of volcanic origin, is 14,408 feet in height.

Volcanic action may become so general at different points along zones of fracture that a row or series of peaks arises which has the appearance of a mountain chain. The Aleutian Islands of Alaska present a mountain range over one thousand miles long that is now being built on the floor of the sea very largely by volcanic activity.

Residual Mountains. Deep erosion working over great periods of time may thoroughly carve up what was formerly a plateau, or tableland region. By intersecting canyons and different rates of erosion residual prominences and peaks may be left. The Grand Canyon has been cut through such a plateau. Doubtless the river, together with its tributaries, will eventually form various residual peaks. In the main canyon, even now, there are isolated pyramids cut out by erosive action that might well be taken for small mountains if they stood out on the level plain.

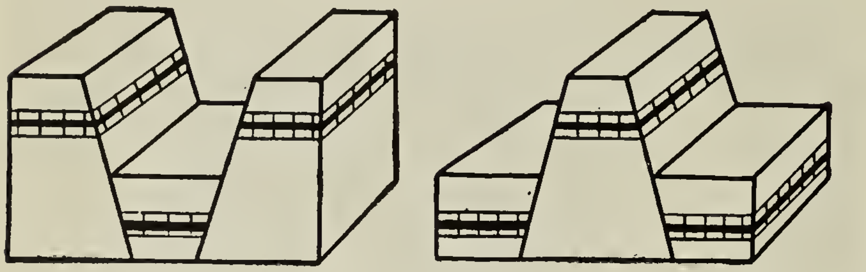


Black Hills Studio

Devil's Tower

A laccolith in Wyoming

Some of the most imposing peaks in Zion National Park in southern Utah are carved from the prominences between tributary valleys. The Catskill Mountains in New York afford an excellent example of mountains hewed out of a former plateau by the forces of erosion. The imposing cream-colored or pinkish spires whose hue varies from hour to hour in the sunshine and which make Bryce Canyon one of the most beautiful natural parks in the world are the product of residual carvings. Anyone who has observed a broken, dissected ridge between two gullies along the roadside has seen a diminutive prominence which, if formed on a much grander scale, would be called a residual mountain.



A diagram to show elevated and depressed blocks due to faulting[1]

Dome Mountains. Dome mountains are formed chiefly by the intrusion of molten magmas between the layers of sedimentary rock. Such intrusions are known as laccoliths. Molten or solidly compressed magmas occur in the interior of the earth either as portions of the original molten earth material or as local reservoirs fused through friction, compression, or radioactivity. Since in times of disturbance the huge crustal blocks move in readjustment, enormous pressure is frequently brought to bear upon these subterranean magmatic bodies. Sometimes the molten mass is forced up by intrusion in between the layers of superimposed strata, causing them to bulge upward so as to take the form of a dome. These domes may be small or very large, depending on both the magnitude of the pressure producing the magma flow and the amount of the magma available. When these intrusions harden, the dome-shaped protuberance may remain as a hill or a mountain, depending on its size. When sufficiently large, they are called *dome mountains*.

Fault Mountains. Fault mountains are believed to have been initiated by earth fractures of great depth. These deep cracks break the earth up into huge blocks, or masses, which set the stage for subsequent shifts. If the region at first was a high plateau, some of the blocks may be depressed several thousand feet, while the adjacent blocks remain in their original position. In other cases one block may be elevated to mountain heights by forces deep beneath the earth's surface which act in a vertical direction. All the blocks, in still other cases, may move downward or upward, but some much farther than others. Occasionally one side of a block may be elevated and the opposite side depressed. The chief result, regardless of the complexity of movements involved, is to leave either whole blocks or parts of them standing much higher than other blocks adjacent to them or than other parts of the same blocks.

If the blocks are relatively small and occur in a series, prominences called *block mountains* may result. If, on the other hand, the blocks are long, a range of block mountains may be formed. One side of such a range will usually have a long, more or less gentle slope, while the other side will be steep and abrupt.

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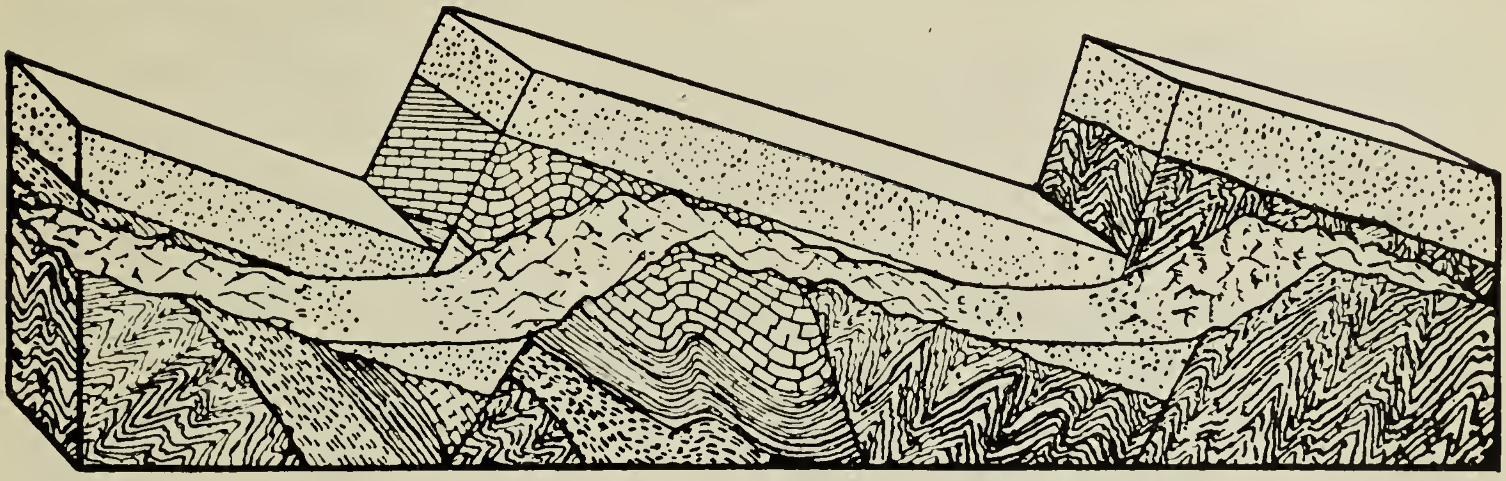
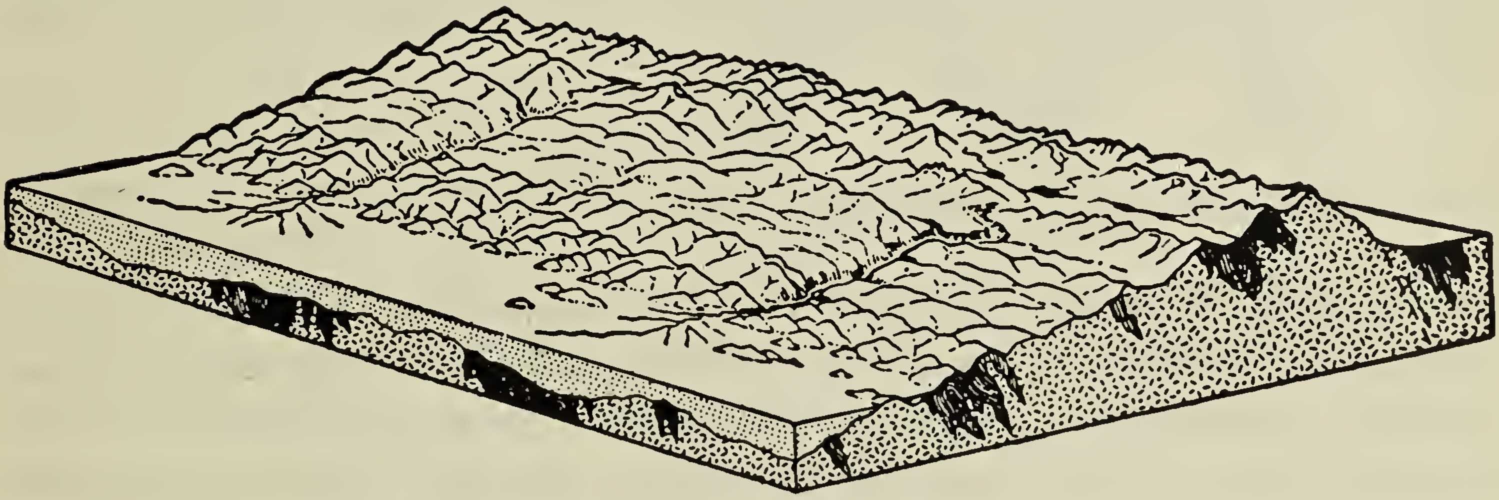
[1] From *Geology*, by Emmons, Thiel, Stauffer, and Allison. By permission of McGraw-Hill Book Company.

Displacement is always followed by weathering and erosion which carve and dissect the escarpment into varied forms and ridges.



A diagram to show erosional mountains (foreground) sculptured from original block fault strata (background)[1]



Generalized form and structure of the Sierra Nevada

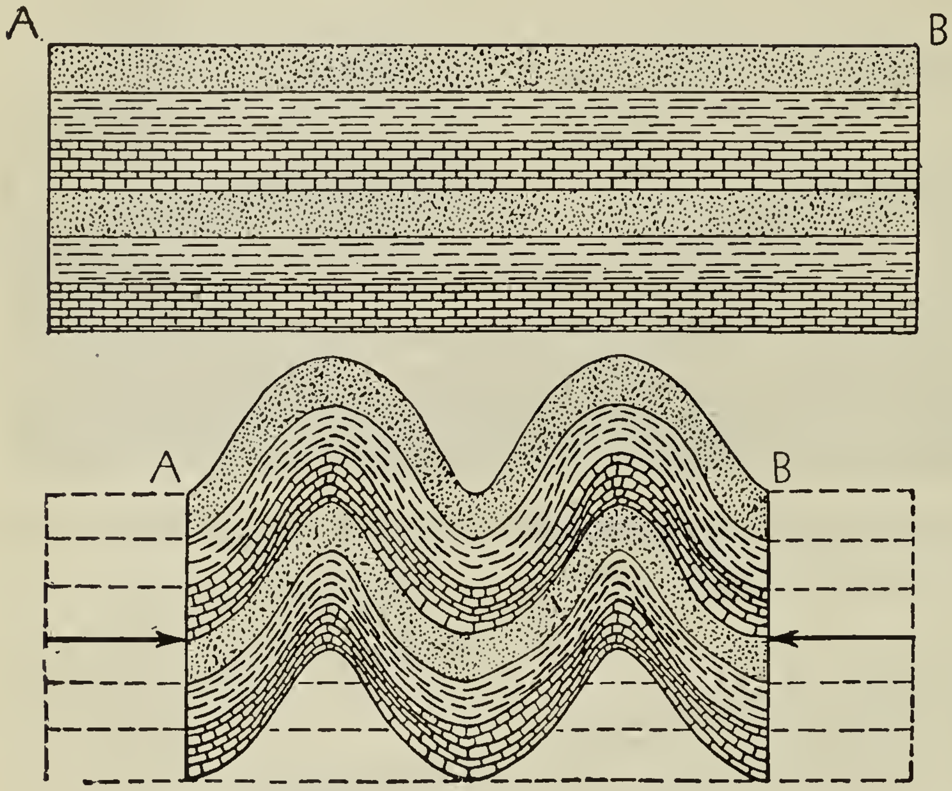
A mountain range sculptured from block-fault strata[2]

The Sierra Nevada of California is a tilted crustal block four hundred miles long and about seventy-five miles wide. The eastern edge of this block has been uplifted to a height of two miles or more to form an abrupt slope facing Owens Valley to the east. The loftiest peak of this range is Mt. Whitney, of the southern Sierras. It is 14,496 feet high and forms the highest elevation in the United States. Owens Valley is the surface of the adjacent block, now greatly modified by erosional deposit, which was not elevated at the outset. The long gradual slope on the west, produced mostly by tilting, extends down to the Valley of California. Here sediments eroded and carried down by stream action have been deposited, in some places, to depths of thousands of feet.

[1] After W. M. Davis. From *Geology*, by Emmons, Thiel, Stauffer, and Allison. By permission of McGraw-Hill Book Company.

[2] After F. E. Matthes. Reprinted by permission from *Textbook of Physical Geology* by Longwell, Knopf, and Flint, published by John Wiley & Sons, Inc.

Folded Mountains. Considering the earth as a whole, the most imposing geological phenomena on the face of the globe are to be found in folded mountains. They, together with their environs, furnish the best clues as to the tremendous age of the earth; and they present the best evidence regarding the manner in which a complex of natural forces may work together to deform the earth's outer crust.



A diagram to show how strata may be folded[1]

According to recent authorities there are three definite stages involved in the development of a folded mountain system. They are (1) the preparatory stage, in which thick layers of sediments accumulate in slowly subsiding troughs in the earth's crust; (2) the period of deformation, during which the deposited strata are subjected to great lateral pressure, which folds them into mountains; (3) the period of denudation through erosion, accompanied or followed by vertical uplifts that tend to revive the mountains.

Let us take the Appalachian system as an example. In ranges of that type it is believed that at some period during geological history their sites were occupied by a long, comparatively narrow depression parallel to the seacoast and sometimes a thousand miles or more in length. This depression the geologists call a *geosyncline.* This formidable word simply means the "earth bent together" and refers to the fact that as the bottom of a depression sank down, the sides tended to bend in together. The beds of these geosynclines seem to have been intrinsically weak. They tended to be paralleled by a similar depression out in the ocean, the two depressions being separated from each other by an elevated strip of land of considerable width. In fact, since the uneroded basaltic sea floor, loaded with silt from the mainland, is considerably denser than the continental areas, it may be the very sinking of this ocean depression, with its attendant horizontal thrust, that caused the intervening strip of land to be buckled up and the floor of the geosyncline to be formed in the first place. The geosyncline at this stage is usually occupied by a great arm of the sea, a delta, or a low-lying swamp. When the trough later to become the Appalachians was down, the ocean extension which submerged it reached out as a shallow sea far westward toward the Missouri River.

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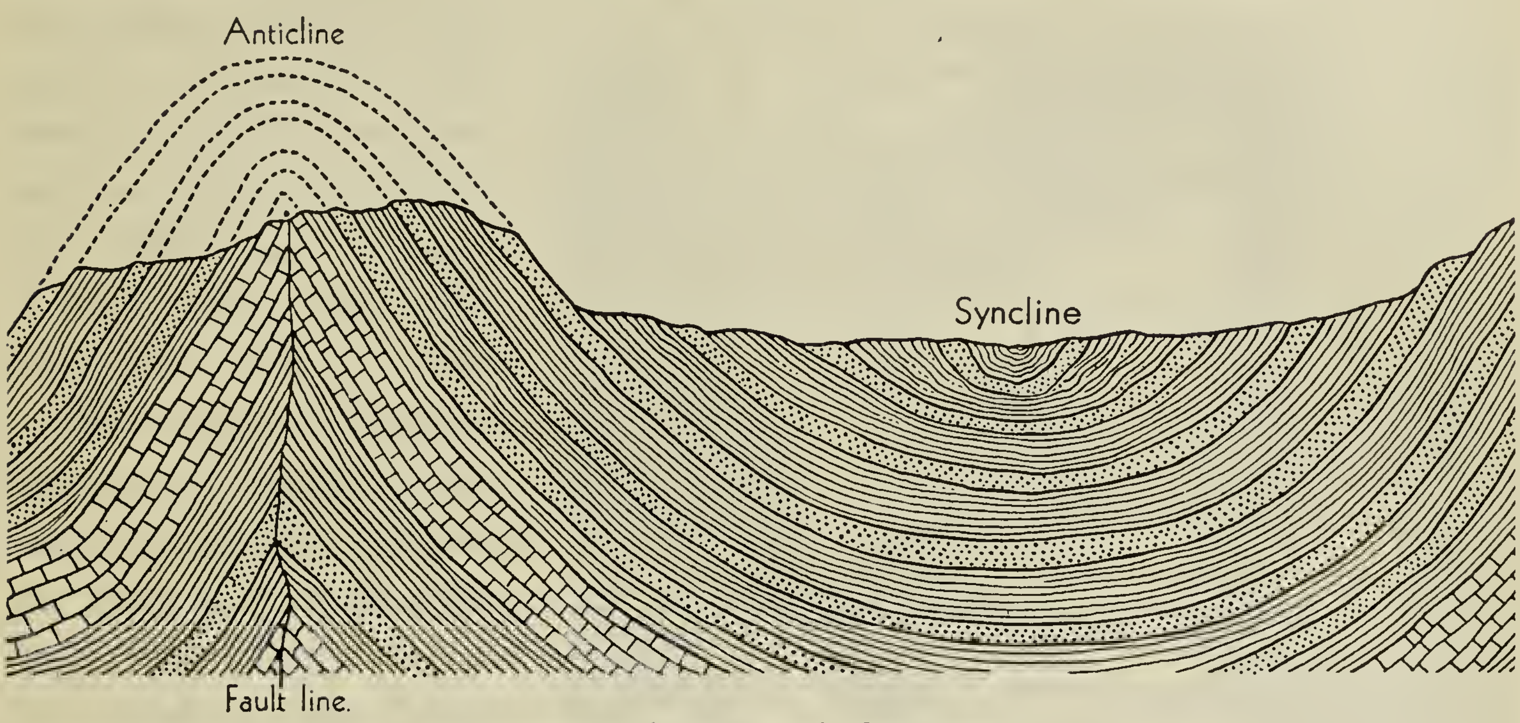
[1] From *Geology,* by Emmons, Thiel, Stauffer, and Allison. By permission of McGraw-Hill Book Company.

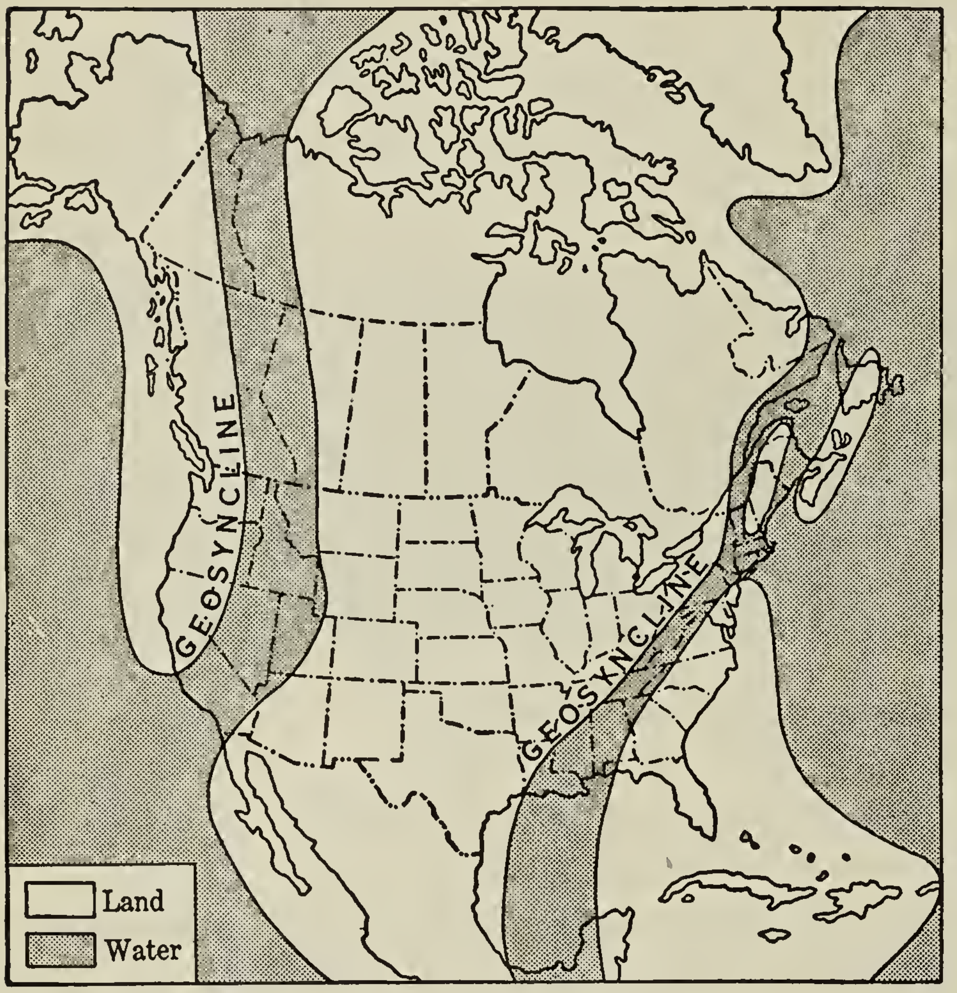


Geosyncline trough formation

As soon as the relative positions of these troughs had been assumed, with the land area intervening, erosion on both sides of the uplifted strip began. The gradient toward the geosyncline was usually steeper; consequently sedimentation in this direction was more rapid. In the case of the Appalachians the elevated land serving as a source of sediment lay close to the east of the present range and is believed to have occupied the continental shelf for some distance out into what is now the Atlantic Ocean. This ancient land, unknown in extent, has been called "Appalachia."

The initial setting seems to have been similar in the case of all folded mountain ranges. The Rocky Mountains occupy the ancient bed of a sea that stretched from the Gulf of California to the Arctic, and the land furnishing the sediment to form them came chiefly from highlands to the west of that sea. The trough from the floor of which the Alps were formed received its sediment from a stretch of old land lying to their north. The Caucasus Mountains derived their component sediments from a land on the south, while at the same period a great sea stretched out northward over what is now Russia. The Andes were formed in a trough into which much sediment was poured from an ancient land, now submerged, on the west.

Erosion from Appalachia, to return to our story, carried a vast amount of eroded material down the western land slope and deposited it along the eastern coast of the adjacent sea. The eroding, transporting agents worked away in a quiet manner for thousands of years, and the total amount of debris laid down by them is astonishing. Geologists tell us that the total depth of the sediment where the mountains now stand averaged twenty thousand feet — almost four miles. Much of this deposit was added, of course, after the subsidence (to be discussed presently) began; and as the sediment was piled upon the floor of the geosyncline, the width of the shallow sea, through continued sinking, increased. This growing deposit of submerged sediment sloped off rather rapidly toward the west. Not far out the depth was but ten thousand feet when deposition was complete; and by the time the location now occupied by the state of Iowa was reached, the deposit had thinned out until it was but four thousand or five thousand feet deep.



Appalachian and Rocky Mountain geosynclines[1]

In the interest of clarity we have oversimplified the process. The movement of the geosyncline was not continuously downward, as has been suggested. On the contrary, structural relations in the series of sediments indicate that the downward bend of the trough was interrupted from time to time by moderate elevations and erosion. The general tendency of movement, however, was downward. Also, the land area, Appalachia, as its thickness, and hence load on the earth's crust, was reduced by erosion, did not form a stationary land mass. Rather it seems to have continued to rise during the period of geosynclinal development.

At this point the stage was set for the second step in folded mountain-building, namely, folding and deformation. The geosyncline, as is generally true, was a zone of crustal weakness. This was indicated by its sinking during long ages of sedimentation. By contrast the earth crust on either side of the geosyncline was relatively strong and unyielding. This condition is also generally to be found. In some way not clearly understood the floor of the geosyncline was gradually squeezed into huge folds, often of great intricacy and complexity, by compression against the side of Appalachia. Under continued lateral squeezing the folds were pushed still higher and the bases brought closer together. By the same action the depressions between the huge ridges were made narrower, deeper, and more precipitous. Not infrequently the lateral compression continued until the folds broke and toppled over on their sides. Indeed, in some cases, they tumbled "heels over head" and, after the disruptive action, lay in a completely inverted position.

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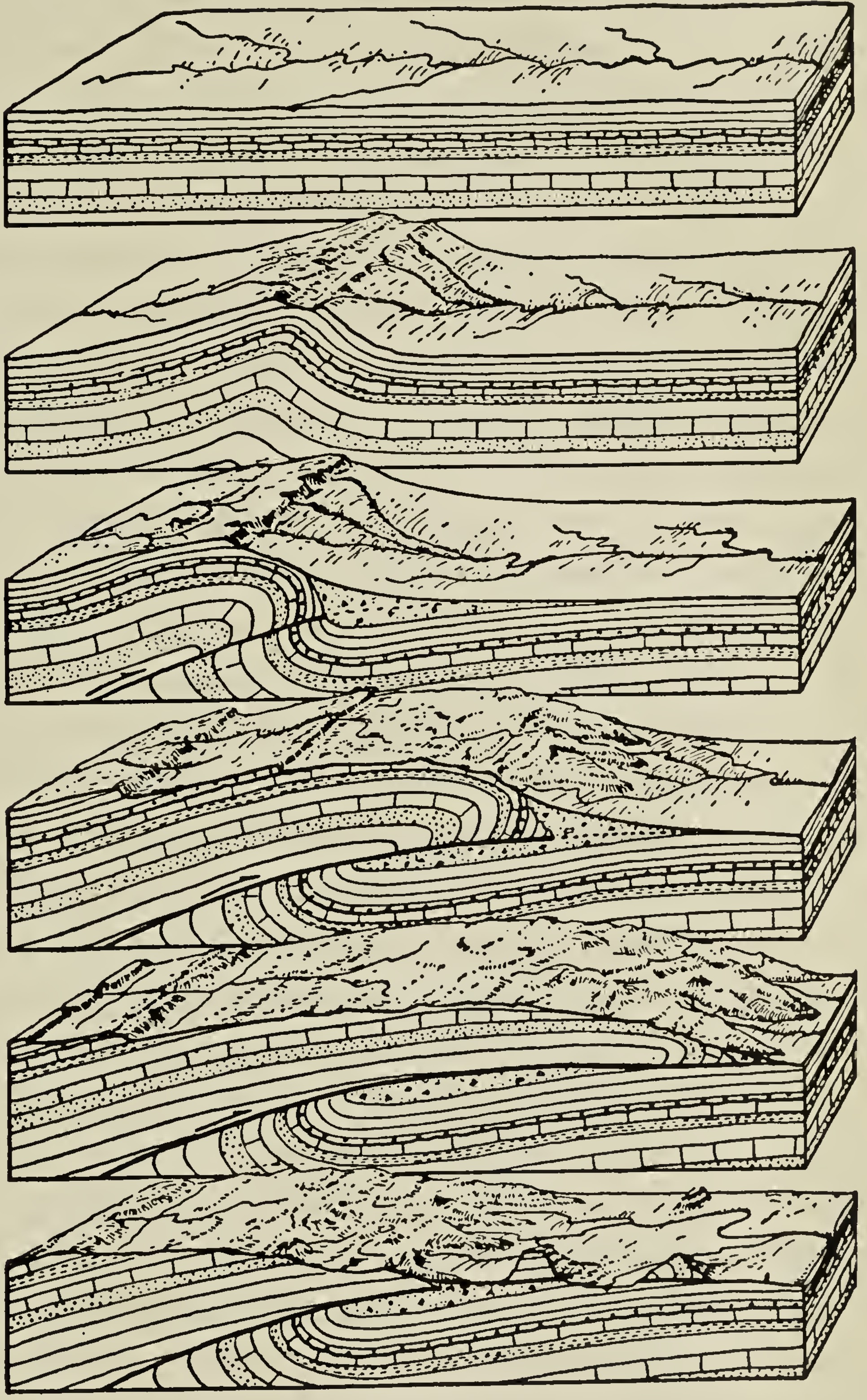
[1] From *Geology*, by Emmons, Thiel, Stauffer, and Allison. By permission of McGraw-Hill Book Company



A series of diagrams to show mountain folding and displacement[1]

In other cases the lateral pressure was exerted so strongly and for such long periods of time that the ridges of the folds broke transversely and the tops were caused to slide over their fractured bases, producing huge displacements known as thrust faults. One wonders at the tremendous forces that must have been required to produce such mass movements of rock against the enormous friction that existed; but one marvels even more at the extent of some of these crustal displacements. It is estimated that in some parts of the Appalachian system the original width of the geosynclinal floor has been decreased about 50 miles by lateral compression. In the Rocky Mountains thrusts of tens of miles are evident; and when the Alps were formed, displacements of one hundred miles or more were produced.

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With the exertion of such compression by these terrestrial vises, one can well imagine the crustal distortion that would naturally take place. The strata were folded, mashed, sliced, and sheared at some points beyond all semblance of their former appearance. Later, in the case of the Rockies, volcanism too was rife. Huge eruptions expelled literally cubic miles of dust, rock, steam, and lava. In some places the magmas did not reach the surface but intruded huge batholiths of molten materials which produced domelike elevations. Invading masses of such igneous material also are especially conspicuous features of the Coast Ranges in western Canada. Here the granite core, now hardened, has been exposed through erosion in a continuous belt eleven hundred miles long. In other places the lava, extruding from great fissures and crevices opened up by crustal faulting and displacement, was poured out in huge lakes about the bases of the mountains and in the valleys between adjacent ranges. Some of the most extensive prehistoric lava beds to be found today are believed to have been formed in this way.

The third stage in the historical development of folded mountains begins as soon as the elevation is lifted high enough to permit the erosive forces to begin their work. For a time both processes may go on together. At length the erosive forces take the ascendancy, and the planing down action begins in earnest. During this stage the degradational agencies reduce the height and ruggedness of the mountainous ridges. Frequently erosion continues until the whole area is planed off to a condition of a flat plain. Such a plateau-like base is called a *peneplain.* The peneplain condition, however, rarely represents the extinction of a mountain range. Subsequent uplifts take place in which the peaks and stream beds are rejuvenated, and secondary stages of erosion follow. The Appalachians, for example, were elevated once, were worked down, were elevated a second time, and now again are well rounded and eroded. The present Rocky Mountains constitute at least the third elevation for that region, as do also the Andes for their region.

We must emphasize that in the long interplay of all these forces the strata have become mixed and commingled to an almost hopeless degree. For this reason and many others, folded mountains constitute the concrete record of the most complicated geological forces known in nature. When deciphered, they also give the most complete story of the past conditions and processes involved in the changes incident to an aging earth.

What We Know about the Nature of the Agencies That Fold and Deform the Earth Is Speculative. We have just attempted to trace in a descriptive manner the stages through which folded mountains are believed to have passed in their development from youth to maturity. When we attempt to assign causes as to how the folding is produced, however, we find ourselves on much more uncertain ground. Indeed, our position must be largely that of theory and speculation.

Isostasy has been assigned as one cause. In its downward movements, so the proponents of this theory believe, the sinking geosyncline would tend to wedge tighter and tighter, which would throw its floor into wrinkled, corrugated folds. Another theory attributes the mountainous elevations and depressions to the cooling and shrinking of the earth, which causes its crust to wrinkle much as an apple shrivels in drying. Still another theory holds that a great expansion in the geosyncline floor would be caused by heat from below as its floor settled downward.

Other causes have been proposed, such as a hypothetical shift in the earth's mass axis. Most of these theories have some points in their favor, but at other points they appear to be inadequate. It is possible that most of the forces mentioned by these theories may have been involved at different stages in mountain-building and to different degrees. It is also possible that still other factors may have been at work which have not yet been uncovered.

The Theory of Isostasy May Be Applied to Explain the Formation of Plateaus. In some instances, as the ocean bed subsides during isostatic movements, there is no neighboring geosyncline in which the stress of lateral pressure can be relieved by the folding of the strata. Under these circumstances large areas of land may be elevated without folding and thus extensive plateaus be formed. It is also possible that other factors may be operative. The plateau comprising the Utah and Nevada basin, with a width of 500 miles, has been uplifted to a height of from 6000 to 8000 feet. By a similar action in South America the great Bolivian plateau was pushed up to from 12,000 to 13,000 feet. It will be seen that these plateau uplifts are much more extensive than the ones that form mountains; and if they do not suffer from an extremely arid climate, or if they do and irrigation water is available, they may form agricultural and grazing lands of great value to man.

The Earth Is Now Believed to Be Very Old. No one can consider a subject like mountain-building without stopping to ask himself, somewhere in the course of his study, just how old the earth must be. As long as the theory of special creation held sway over the minds of men, the age of the earth did not matter much. The most exacting scientist of that period could accept Archbishop Ussher's pronouncement regarding the time of creation with full complacency. As a result of careful study of the Scriptures, he is reputed to have declared in 1654 that "heaven and earth, center and circumference, were made in the same instant of time, and clouds full of water, and man were created by the Trinity on the twenty-sixth day of October, 4004 B.C., at nine o'clock in the morning."

But just as soon as men began to approach the study of the earth itself and the living things found on it from the developmental point of view, they began seriously to question the whole idea that the earth is but six or eight thousand years old. It is evident that if, as a preliminary to mountain-building, literally miles of sediment must have been laid down on the bottom of a geosyncline by the comparatively slow processes of erosion and deposition, it would have taken a long time to do it. The first Appalachian deposit is estimated to have required millions of years. If then, after this prerequisite deposit was made, it possibly took millions of years more of tremendous squeezing between the crustal blocks of the earth to compress the bottom of the trough into folds, and, lastly, if a third vast period of time was involved in the final elevation of the range, then it is obvious that estimates of a few thousand years for the age of the earth are entirely inadequate.

So, because of these considerations, geologists and paleontologists have had to revise their former ideas completely as to the age of the earth. They attempt now to get at the problem in a scientific manner. By this we mean that they assemble all the facts from the rocks, fossils, mountains, and earth's strata that they possibly can, put them together, and carefully study them.

The Age of the Earth Has Been Estimated by Various Methods. The amount of salt in the sea is one method of attack. It is believed that the waters of the ocean at the beginning were fresh, like those of the land. As water from the land flowed to the ocean, however, it carried a small burden of dissolved salt with it. The waters of the ocean in turn evaporated and returned to the land as fresh water to bring back again to the sea a tiny load of salt. This cycle has continued throughout most of geological time. Now by computing the amount of salt carried to the sea annually in this way and by making an estimate of the total salt found in the ocean, earth scientists have arrived at a figure for the age of the earth.

In using this method, however, there are certain complicating factors. We have no assurance that the continental areas from which salt has been transported into the sea have remained the same; in fact, there is considerable evidence to show that they have not. The amount of salt carried by high water in times of flood is obviously less than during periods of normal flow, when it moves along leisurely. The saline concentration of land water now may vary considerably from that of early geological times; moreover, no one knows how much salt has been dissolved by the ocean waters from the floor of the seas themselves. And finally, it is known that through subsequent elevation great quantities of salt once deposited in the ocean have been lifted up and made a part of the land again (see page 576). Despite these uncertainties, however, since about 400,000,000 tons of salt is estimated to reach the sea annually, and since the total salt computed for all the oceans is 40,000,000,000,000,000 tons, the ultimate figure for the age of the earth, on this basis, comes to about a hundred million years. This was an astounding disclosure as contrasted with the former six-thousand-year estimate.

Another computation as to the earth's age is based on the amount and rate of sedimentation. The sedimentary rocks of the earth laid down from the beginning of time have been judged to have a maximum thickness of three hundred and fifty thousand feet. If this pile of sediment carried by the waters of the earth should have been laid down continuously at the same rate that the river Nile is now building up its delta, the total deposition would have required about twelve million years. But we know that this could not have been. The Nile, except in its lower stretches, is a rapidly cutting stream. The waters of most other rivers do not erode so rapidly. So nothing but a rough estimate as to the age of the earth can be made on this basis. An average of several estimates, however, places the rate of general sedimentation at one foot in eight hundred and eighty years. On this basis, then, the earth would be approximately three hundred million years old.

A new and apparently more reliable method of getting at the earth's age is the approach through the results of radioactive disintegrations. Thus lead is known to have several isotopes, ranging in weight from 204 to 208; but the one formed by the decomposition of uranium, which is generally used in these estimates, has an atomic weight of 206 and can be identified by this characteristic. Lead of this character can be found as a deposit at many places in the earth's crust. Presumably, then, it came from uranium decomposition through radioactive changes. But these changes require an enormous amount of time for their completion. Indeed, the complete transition would require billions of years.

In the earth in many places these transformations are not yet completed. There is some uranium left, as well as intermediate products; but there is also some lead with an atomic weight of 206, and, upon the basis of the amount of it present, estimates as to the age of the earth are made. Hall and Richards of Harvard, after an extensive investigation of the amount of lead found and the uranium still remaining in the Black Hills of South Dakota, have placed their estimate of the age of the earth at 1,667,000,000 years. By the same method Ellsworth of Ottawa has placed the age of the oldest rocks in Canada at over 1,000,000,000 years. At Karelia, Finland, the age of the rocks has been estimated by this method to be 1,850,000,000 years.

In this method of estimating the age of the earth, as in all others, there are elements of uncertainty which must be taken into account. In the first place, there might have been some uranium lead resident in the rocks as a part of the original earth material. Moreover, it is not known that uranium has always decomposed at its present rate.

Nevertheless, when the original figures are subjected to all the corrections that conservative geophysicists can impose, the verdicts all point to the same conclusion; that is, that the earth is exceedingly old—very much older, in fact, than up to within twenty-five years ago it was ever dreamed to be. It is now generally accepted that the earth has been in existence for at least a billion and a half to two billion years. Some estimates even place the figures considerably higher than that.

Such are the revelations of science. Archbishop Ussher—and he was an admirable man—arrived at his conclusions by bringing together all the data he could that, in his judgment, had a bearing on the question. But his data were faulty and incomplete. He should have gone to the mountains, rocks, and minerals, the very handiwork of the creative forces in nature, to see what they showed. For their testimony in this case constitutes what would be called in a court of law the material evidence. In their bodies they bear literally the very substances, marks, and designs produced by these cosmic changes. But we can forgive the honest bishop for his error, for comparatively little was known at that time about the earth's structure and its geology. Our knowledge of the rocks has greatly expanded since then, and because of this new knowledge we are better able to determine the age of the earth than was Archbishop Ussher. This is also another evidence that man's feet are directed along the highways leading to the goal of scientific truth only as he digs about, uncovers nature's facts, and lets them guide him in his progress.

Geological Changes Are in a State of Constant Progress. In this and the preceding chapter we have found that the earth is subject to great alternating forces of uplift and degradation. The ocean bed sinks and mountains are elevated. The mountains in turn wear down; this material, carried to the ocean by transporting agents, is added to the weight of the ocean floor. This increased weight causes it to sink, and a readjustment to restore equilibrium pushes the mountains up again. In a sense the earth is in a state of rhythm all the time. It sinks in one place and rises in another. So the story has run for hundreds of millions of years. What we often take for a quiet and complacent earth is anything but that! It is a scene of monumental forces acting slowly but on a grand and sublime scale.

It is very likely that these changes during the early period of the earth's history were more numerous and violent than now; but that they are continuing today we have ample evidence. And there is no indication that these great crustal shifts will soon cease. On the contrary, every evidence that has yet been discovered points to the inevitable conclusion that they will continue for hundreds of millions of years after this generation has made its contribution to human history and has passed off the stage of action.

Questions for Study

1. What are the forces believed to be responsible for building up the land areas?
2. In what different ways may the forces of aggradation build up land areas?
3. What evidence is there that the temperature at great depths beneath the earth's surface is much higher than that at the surface?
4. How can hot springs and geysers be explained?
5. What theoretical explanation is advanced by geologists to account for the high temperatures believed to exist at great depths in the earth's crust?
6. What evidences can you give from everyday life that support the theory of flowage?
7. How does the theory of isostasy explain surface movements of the earth's crust?
8. How does the elastic-earth theory explain the shifts which take place in the earth's crust?
9. What geological evidences can you present that point to actual shifts of levels in the earth's surface?
10. What modern theories attempt to explain earthquakes?
11. How would you explain the fact that the Pacific-coast region of the United States has been subject to minor and major earthquakes?
12. How is it possible for a modern scientist, though far distant from the site of an earthquake, to know that an earthquake is taking place, its severity, and about where it is taking place?
13. How are the different types of mountains believed to have been formed?
14. In many of the mountain regions of the states of Colorado and Wyoming, coal is found at elevations of 8000 feet above sea level. How would you explain this fact?
15. What are the great plateau regions of the United States? How does the geologist explain their formation?
16. By what methods do geologists estimate the age of the earth?

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CHAPTER THIRTY

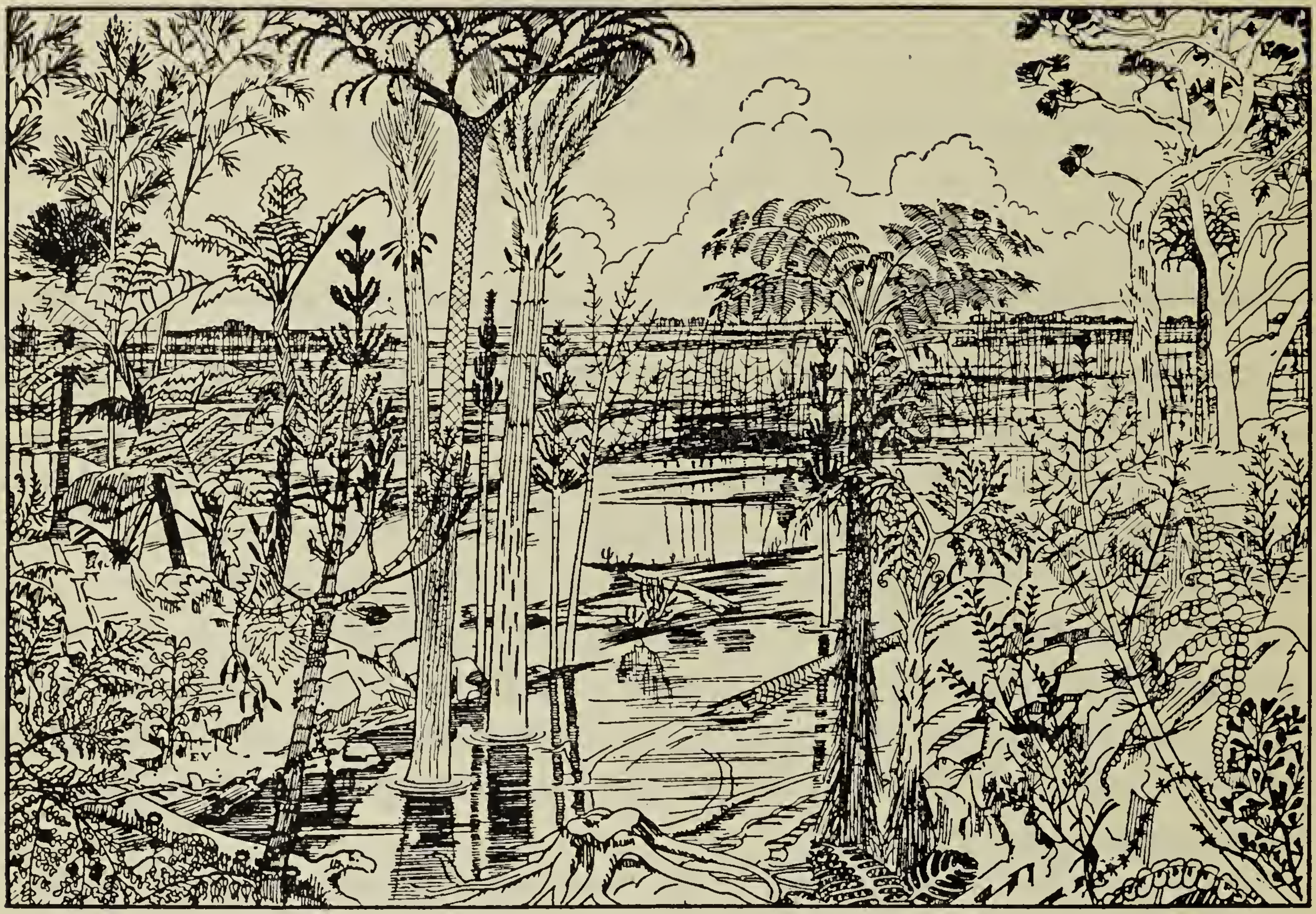
Geological Forces Have Produced Many Products of Value to Man

Coal Has Been Formed by Geological Processes. Coal deposits are widely scattered over the earth, appearing to some extent in every continent, including Australia. Those of North America, however, are by far the most extensive known, the most varied as to character, and the most valuable. While there are other contributing factors, without question the rapid strides which the people of the United States have made politically and industrially toward world leadership during the last century would have been quite impossible had it not been for the country's rich beds of coal. Canada is also well supplied with coal, and our Alaskan possession has valuable deposits of it which are as yet comparatively untouched.

Geologists believe that coal is the carbonized residue of plant remains. There is abundant evidence to support this conclusion. Some of the softer coals, such as lignite, still retain unmistakable evidences of their origin. It is not unusual to find sections of coal from lignite mines in which the rings of trees or the grain of the wood from which the coal was derived can be detected. Moreover, embedded in the shale layers immediately below coal beds the preserved remains of old tree stumps and their heavier roots may be found. E. C. Jeffrey, by examining microscopically very thin sections of certain coals, has discovered that they were formed almost exclusively from the spores of certain prehistoric plants.

For heavy coal beds to form, it is believed by most geologists that a warm, humid climate and possibly an atmosphere more heavily charged with carbon dioxide than exists at present were necessary prerequisites. The location of coal beds was probably in the swampy delta of some large river or in some great swampy geosyncline extension from the then dilutely saline sea. The rich, extensive coal fields of the Appalachian area are believed to have been formed in the great Appalachian geosyncline discussed in the last chapter.

Under these highly favorable conditions a rank growth of vegetation adapted to swamp life would spring up. The greatest coal beds seem to have been covered with forests of giant ferns, horsetails, and club mosses now long extinct. Many of the ferns in those days were of treelike proportions, and the slender little scouring rushes now extant were then represented by tall,



Types of vegetation in coal-forming forests[1]

jointed plants stretching up seventy or eighty feet and having a diameter of six inches or more. The club mosses of that period, now represented by diminutive plants used for Christmas decorations, were widely branched giants often a hundred feet or more in height. These strange plants flourished in the swamps of that day and formed impenetrable thickets, much as the bamboos of today do.

Following a period of rapid and luxuriant growth in which heavy layers of leaves, stems, twigs, and roots developed (this may have required several centuries), conditions arose that buried this plant mass under layers of mud, sediment, and water. This may have come about through the subsidence of the swamp itself or by an elevation of the surrounding land that quickened erosion and deposit.

Now, under a cover so moist as largely to exclude oxygen, and subjected to the pressure of the superposed sediment and water, this layer of vegetation was under conditions highly favorable to coal formation. It could not decay to any great extent because of oxygen deficiency; so it was gradually compacted and metamorphosed into coal. During this process water, carbon

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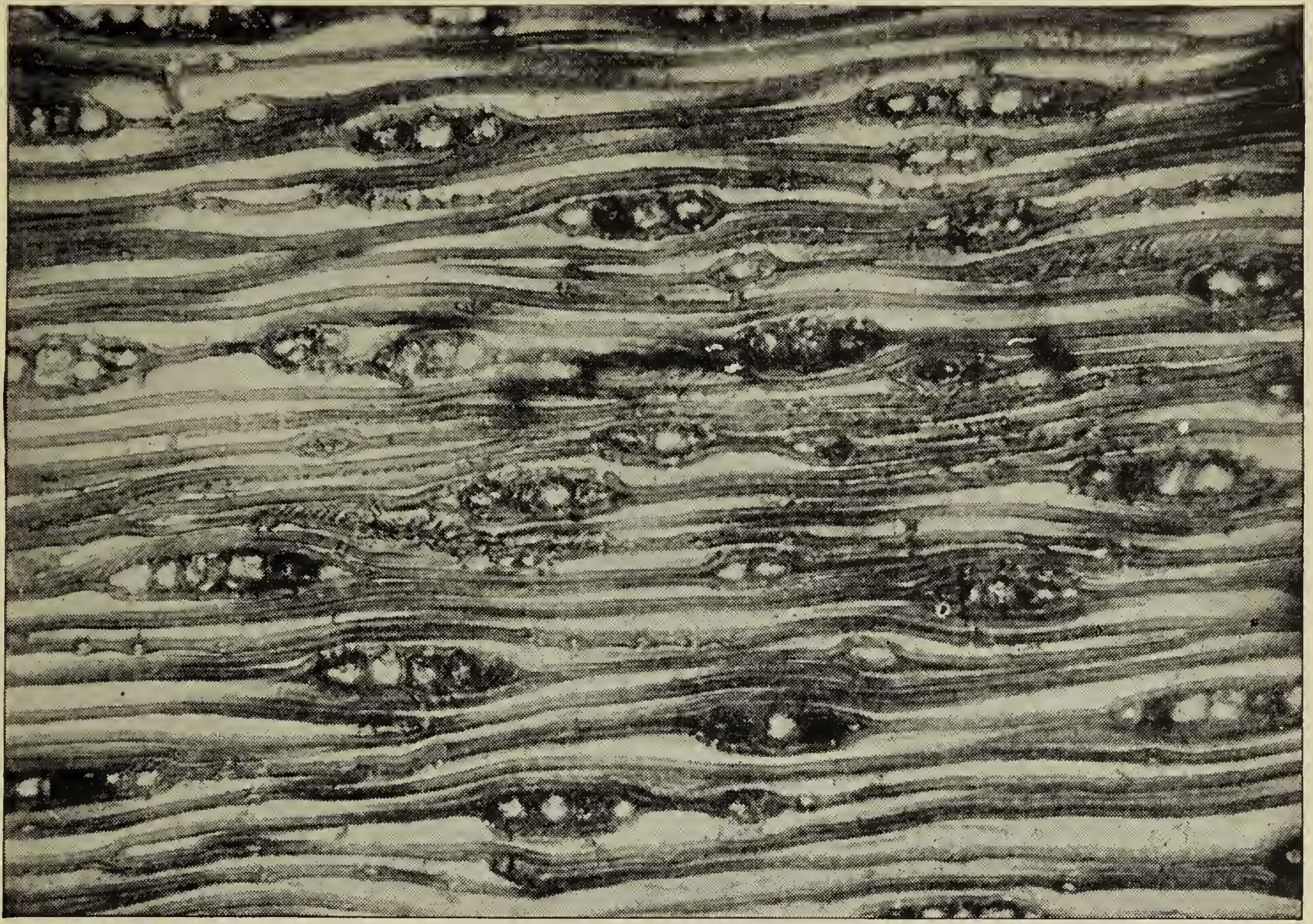
[1] From *Plant Life through the Ages*, by A. C. Seward (drawing by E. Vulliamy). By permission of the Cambridge University Press.



Photomicrograph of a thin section of lignite showing plant tissue structure

Entrance to an anthracite mine

United States Geological Survey

Layers of bituminous coal interspersed with layers of clay

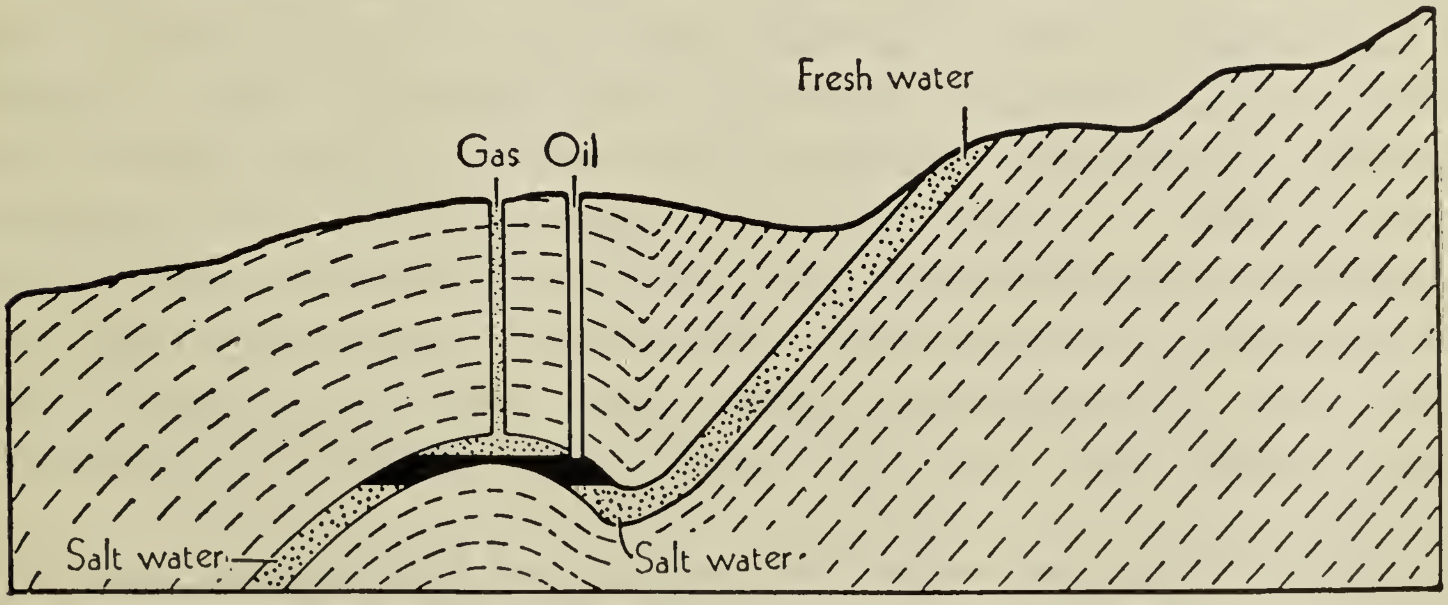
dioxide, carbon monoxide, marsh gas, and other gases were distilled off in great quantities, leaving behind a residue of much more nearly pure carbon, or coal.

Petroleum Is Believed to Have Been Derived through Geological Processes. Closely related to coal as to origin are petroleum and natural gas. They too are believed to have been derived from organic matter, either plant or animal, but it is probable that plant remains furnished the most of these natural products. Although coal appears to have been mostly the derivative of mosses and higher plant tissues, it seems probable that much of the oil and gas deposits came from the lower types of plants, especially algae. It is possible, too, that the simpler animal remains, including fish, furnished considerable quantities of it.

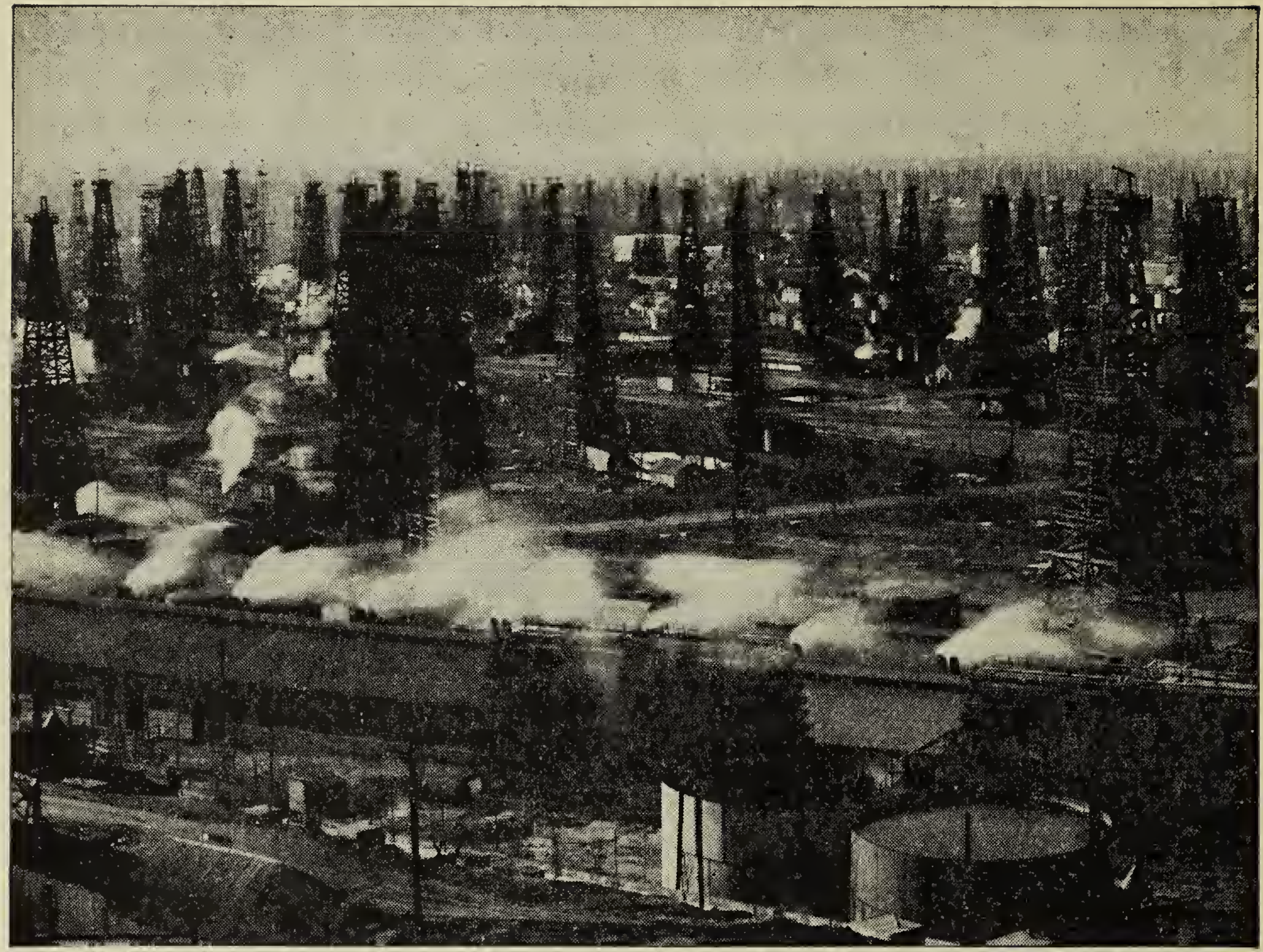
Petroleum and gas are believed to have been formed mostly in connection with the shale beds of marine waters. One support for this belief is that salty water is commonly found associated with oil and gas deposits. Great masses of animal and plant bodies were inundated and suffered bacterial decomposition, resulting, as is held by some geologists, in the production of a kind of solid fat called *kerogen*. Subsequently this solid fat was buried under deep sediment and subjected to great pressure and heat. Under these conditions the kerogen passed over into liquid oil and natural gas. Originally the petroleum was developed in the shaly layers of former sea beds, but it was later pushed out into the more porous sandstone strata by the capillary action of the salt water. If one saturates a piece of shale with oil in the laboratory and then inserts one end of the shale in a basin of water, the oil is gradually displaced by the water and is driven out to the surface. This action perhaps accounts for the fact that most of the oil deposits are encountered in sandstone layers. In some sandstone 20 per cent or more of the volume is pore space, which affords an excellent retreat and reservoir for the oil as it is forced out of the adjacent layers of shale. The productive sands may vary from a few feet in thickness to fifty feet or more. Some oil is also found associated with porous limestone.

Oil Is Often Accumulated in Structures Called Domes. One of the common types of oil deposit is that of the oil dome, which is formed by a domelike upward curve of the hard, impervious cap rock usually found extending like a roof over the oil-bearing sands. The gas, being lighter, accumulates in the top of the dome, with a layer of oil-bearing sandstone below, which in turn is followed by a stratum saturated with heavy salt water. Because of the weight of the superimposed layers, the whole is subject to great pressure.

If now a well be bored into the gas chamber from directly above, it becomes a gas well chiefly, with perhaps some petroleum included in the flow. If the oil below the gas is removed through this opening, it must be pumped out. On the other hand, if the well be bored farther down on the side of the dome so as to penetrate directly from the cap rock into the oil-bearing sands, ideal conditions for a producing well are fulfilled. The tremendous gas pressure above forces the oil upward through the bore and produces the most desirable type of flowing well.



A diagram to show how gas and oil may be imprisoned in the earth



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Oil derricks on Signal Hill, California

After the oil level has been lowered to the level of the well bottom, the well then becomes a gas well, which may maintain a long and profitable flow for its owners. Whatever oil is left below this level must be reached by deepening the well, by pumping, or by drilling a new well farther down the side of the dome. Finally, when all the gas and oil originally contained in the dome have been exhausted, salt water begins to flow, and the well is abandoned.

Asphaltum Is Believed to Have Been Derived from Petroleum. Some oils have a heavy asphaltic base left after the lighter and more volatile oils are drawn off by special processes. This residue is a tarlike substance used mostly for fuel. It appears that in some regions these lighter oils were either distilled off or leached away by natural processes, leaving a very heavy, black, viscid asphaltum deposit behind. These deposits constitute our asphaltum beds, and are the source of the asphalt used in making pavements and highways. Asphalt deposits are found extensively on the island of Trinidad and in Venezuela.

At Rancho La Brea, within the city limits of Los Angeles, a prehistoric lake of asphaltum has been discovered from which the fossil remains of many

An asphalt pit at Rancho La Brea, California

Note the bubbles where gas is being emitted

animals have been recovered. It seems that in prehistoric times pools of water must have gathered in the impervious depressions, and mammals and birds were caught in the heavy, sticky asphaltum as they came to slake their thirst. Carnivorous animals, seeking to devour these luckless victims as prey, were themselves entrapped, and they all perished together. After the flesh had decayed away, the bones became embedded in the tarry mass, from which they may now be excavated in great quantities and in a remarkably good state of preservation. Some of the most valuable fossil remains now exhibited in the Los Angeles Museum have been taken from this pit.

Salt Is a Common Article of Diet. Salt is such a common and necessary article of food among civilized men that we are likely to take it for granted that all peoples everywhere always used it. Such is not the case. Many primitive people, who lived remote from the sea and whose geographical location did not make natural saline deposits available, not only did not use salt as an accessory food but seem to have been quite unaware of its existence. Once people acquired a taste for salt, however, they would go to almost any limits to obtain it. The same holds true for many other higher mammals, such as cattle, horses, sheep, and deer. Well-beaten paths leading to natural "salt licks" have often been made by wild animals as they came in from bush and plain.

Salt Beds Are Believed to Have Been Formed by a Slow Concentration of Dilute Saline Water. The components of common table salt, sodium and chlorine, originally came from the igneous rock making up the earth's crust. Throughout the geological ages of the past salt has gradually weathered and leached out of this rock and has been carried as a dilute saline solution down to the sea or into certain landlocked lakes. Although ocean water, as we have found, contains approximately only 3 per cent of salt on an average, yet the total amount of salt held in solution in this way is astonishing. It has been estimated that if all the oceans could be evaporated to dryness, they would yield four and a half million cubic miles of rock salt, or fourteen and a half times the entire land volume of Europe above high-water mark.

Ever since the Silurian period special deposits of rock salt have been formed from time to time by the combined action of geological and atmospheric forces. During the Silurian, which was a geological age estimated to have occurred about two hundred and twenty-five million years ago, the areas of the seas swelled greatly. This has been attributed to an increase of the hydrosphere through heavy volcanic action and to rapid erosion, which tended to fill the ocean and raise the water level. The cause assigned, however, must be taken as highly theoretical. No one knows positively the agencies at work to produce such a land-water relation.

Near the close of this period almost half of North America was covered with broad shallow seas. The same conditions prevailed in Europe, Asia, Australia, and South America. Then followed a period of crustal quiet, succeeded by an age of apparent contraction. During the time of this crustal shrinking, there are believed to have been formed in these shallow seas depressions which filled with marine water. Now followed elevation and long expanses of time in which evaporation gradually dried up the depressions, leaving the salt content behind as beds of rock salt. In some cases depressions near the ocean, because of a shifting of relative land and water levels, were repeatedly replenished and evaporated, which made the salt deposit surprisingly deep. In other cases, because of alternate shifting of levels, successive strata of salt have been laid down interspersed with layers of other sedimentary material, the whole comprising a salt formation hundreds of feet thick.

At Ithaca, New York, there are seven alternate layers of shale and salt, with each of the fourteen beds averaging about 35 feet in thickness. In New

York a total area of from 9000 to 10,000 square miles has a single bed of salt from 40 to 80 feet thick. Heavy salt deposits are also found in Ohio, Kansas, Texas, Louisiana, and California. In some places, such as Great Salt Lake, the prolonged evaporation of comparatively fresh water has resulted in salt deposits.

Igneous Rock Is Believed to Have Been the Original Source of Metallic Ores. Metallic ores as valuable geological products stand out, with reference to place of origin, in sharp contrast to the other products which we have just been studying. Coal, oil, and salt had their genesis on the surface, whereas the ores had their source down in the earth's inner regions. How deep down is not known. They may have come from a vast reservoir remote from the surface, or they may have issued from localized deposits scattered about through the earth's crust at a shallower depth.

Two facts of which geologists feel sure are that the ores came originally from the igneous rocks and that they are found in mountainous regions. Very rarely, indeed, are ore deposits found outside the neighborhood of mountain formations. When they are, the metal either has been transported and deposited there by some agent, such as water, or has been concentrated there as a heavier substance left behind when old mountains occupying that site were torn down and the lighter substances carried away by erosion. The close connection between mountains and ores is revealed in the appropriate term which the Germans use for mining. They call it *bergwerk*, which, literally translated, means "mountain work."

Since the exterior of the earth has been changed greatly by geological forces during the great aeons of its history, it is probable that none of the igneous rock which may have formed its original surface crust is now left intact. It has been ground up and built into mantle, sedimentary, and metamorphic rock. During these processes the heavier metals would have a tendency to settle down gradually out of the reach of man; and if the earth material at the outset were molten, the heavier substances would have been pulled down even more easily at that time by the sorting force of gravity. So whatever ores are available today must have been carried up from variable depths by subsequent magmatic flows forced up from below.

Under these conditions mountainous districts would form the great repositories in which nature's valuable ores would be found. It is in these regions that the rocks are upheaved, folded, warped, domed, and faulted. Here magma, welling up from the earth's interior, has injected enormous deposits into chambers and cavities produced between the more yielding layers of sedimentary rocks above—giant internal seas of molten material sometimes over a thousand miles long, two hundred or three hundred miles wide, and of unknown depth. These intrusions formed the very heart and core of whole mountain ranges, as well as the more segregated peaks. Under tremendous internal pressure this magma was squeezed upward to fill every fissure, crack, crevice, chamber, and pore that it could reach, and in this manner it formed all sorts of intersecting and crisscross patterns. These are the sites of many of the veins and lodes worked commercially today.

As a rule, the metalliferous materials were diffusely scattered through a great volume of molten magma. Except in certain special instances, the ore deposits would have been of far too low a grade for man to work profitably had they not been condensed by subsequent natural forces.

Iron ore runs from 25 to 70 per cent iron; zinc ore, from 3 to 25 per cent zinc; lead ore, from 3 to 15 per cent lead. Copper ores usually are of much lower grade, the bulk of this metal being derived from ores that run from 0.75 to 5 per cent copper. Silver and gold, as would be expected, can be profitably recovered from ores of much lower metallic content. Silver runs from 8 to 30 ounces or more per ton, and gold from $3 to $10 per ton. Many ores contain not only one but two or even three or more metals in paying proportions. Thus silver and gold are frequently found together, as are lead and zinc. There are few copper ores that do not contain some gold or silver and frequently both.

Some Ores Have Been Concentrated through Magmatic Segregation. In some instances it seems that metallic ores have become concentrated through what is termed magmatic segregation. As the flowing magma, in its movement, reaches areas where it begins to cool, or as other changes take place, certain constituents tend to segregate out. This segregation in the magma may be due to the influence of gravity acting on the different densities of its component parts. When a cake mixture is too thin, for example, the raisins will settle to the bottom while it is being baked. The segregation of ores may also occur as a result of the different saturation points for the constituent materials. This often causes one kind of substance in a complex solution to solidify before the others do. This would tend to segregate it; in fact, whole series of segregates might be formed in this way from substances as complicated as certain magmas must have been.

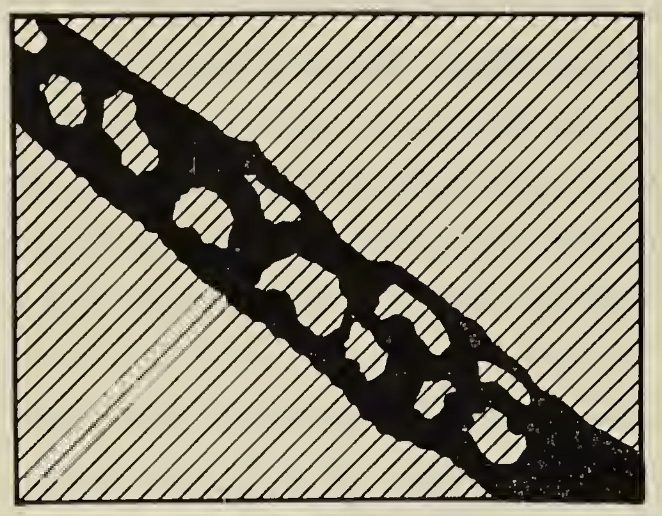
Although magmatic segregation has not concentrated nearly so many profitable ore bodies as have other forces, to be noted later, still it does account for some extremely valuable metallic deposits. Certain very extensive bodies of magmatic iron ore probably have been formed in this way. At Sudbury, Ontario, there are enormous aggregates of the richest kind of nickel-copper ores that have been separated from the surrounding rocks in this manner. Some of the great platinum deposits recently discovered in South Africa are also of this type.

The Most Extensive Bodies of Metallic Ores Have Been Concentrated from Igneous Rocks by Natural Agents. By far the most extensive bodies of metallic ores, however, have been formed by a concentration of one kind or another that has taken place after the igneous metal-bearing rocks were hardened. In this connection our purpose will be fulfilled if we note only three or four of the main agents of deposit.

Gases are believed to have been active in ore concentration. Volcanic magmas and lavas are known to contain a large volume of different gases. Steam, carbon dioxide, sulfur gases, and many others are common products of volcanism. Down in the earth's interior these gases exist under high pressure and are heated to very high temperatures. These conditions are favorable to the partial volatilization of many metals. Mercury volatilizes easily, and tests made of gases emitted in the Valley of Ten Thousand Smokes in Alaska prove conclusively that other metals may be carried in this way. As these gases, laden with mineral vapor, pass through crevices or along the walls of magma-filled fissures and cracks on their way to the surface, their pressure is reduced, their temperature is lowered, and the gas-borne metals tend to congeal out and become deposited along the edge of the residual rocks. Here they form the veins so eagerly sought by the prospector as he attempts to exploit nature's riches for man's benefit.

Water, both hot and cold, is an efficient agent of ore deposition also. Hot water, often abundantly associated with igneous rocks, dissolves certain minerals which in turn make it an active solvent of ores of various kinds. Now, as the water moves along, it becomes cooled and drops some of these dissolved ores; or it reacts chemically with other minerals it encounters, in such a way as to take on new solutes and to precipitate out the metal-bearing compounds and leave them behind. Ore deposits made in this way are likely to be laid down in veins because the magma, intruded into these crevices and cracks, not only furnished the ore-bearing minerals to start with, but also, because of contraction in cooling, furnished tiny passageways through which the hot water traveled on its way to the surface.

Deposition by artesian waters is believed to be responsible for the great zinc and lead beds found in southwestern Wisconsin, in eastern Tennessee, and in the Ozarks of southwestern Missouri. The great silver-lead-zinc ore region near Leadville, Colorado, is water-deposited and has furnished metals valued at $450,000,000. The most productive copper deposits in the world, at Butte, Montana, occur in fissure veins and have yielded over 8,000,000,000 pounds of copper, 400,000,000 ounces of silver, and 2,000,000 ounces of gold, besides large quantities of zinc.



How metallic ore may replace rock structures in forming veins

The diagonally ruled portion represents rock structures; the black area, the metallic replacement

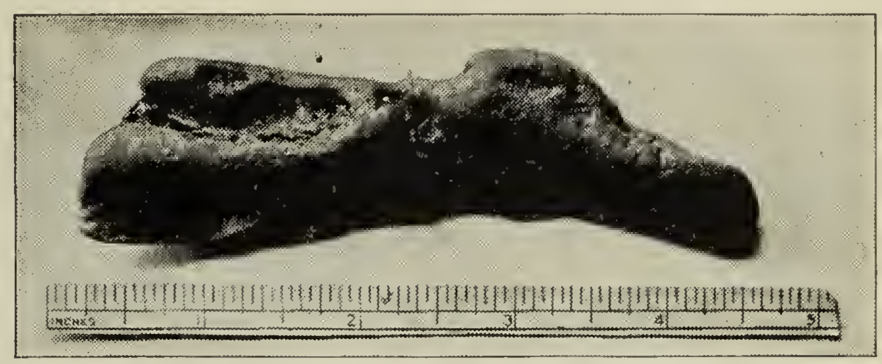
Sometimes rain water, percolating down from the surface, dissolves out metal-bearing minerals and redeposits them at lower levels. In other cases surface water may carry ores in suspension downward, and they may be strained out and left when the water encounters pores too small to permit the passage of the ore-bearing particles.

The great hematite beds extending along the Appalachian system from New York to Alabama are believed to have been concentrated through the action of water, just as beds of any ordinary sediment may be deposited. The most important iron-ore repositories of this sort known in the world are to be found in Lorraine, France, where the original deposit has been estimated at about five billion tons. It is also probable that much of the metal laid down in the iron mines in the Lake Superior region was embedded in this manner, supplemented, perhaps, by bacterial action.

In some instances ore deposits have been known to be concentrated by residual action. Especially is this true in the case of certain gold deposits. Since this metal has a specific gravity about six times that of ordinary rock, it is more difficult for water or wind to transport it. For this reason gold-bearing rocks often disintegrate and then have their lighter components either washed away or blown away, leaving the gold behind in a more concentrated form. In some districts in the southern Appalachians the rotten outcrops have been panned for gold accumulated in this manner.

Placer gold-mining, one of the most valuable sources of gold in the world, has been made possible largely through the assorting action of water and gravity on this heavy metal. As the original gold-bearing rocks weathered and their remains were washed away by rapid mountain streams, the dense gold particles tended to be dropped first, while the lighter pebbles, sand, and silt were transported farther down the slope. The result was, in some localities, a great natural assorting process carried on for thousands of years and resulting in fabulous deposits of gold ("bonanzas," as they are called when discovered).

The great gold-bearing sands of California that caused the gold rush of '49, as well as the famous bonanza strike in Alaska, are water-deposited beds of this character. In California the mother lode from which the gold came originally consisted of a series of comparatively low-grade parallel veins scattered through strata of various kinds of rock. The whole series is scarcely more than a mile wide but is over a hundred miles long. The formation, for the most part, is tipped over so as to make a rather sharp dip downward. Occasionally very rich pockets occur, but as a rule the veins assay only about $3 to $4 a ton. Throughout the ages thousands of feet must have been eroded off the top of this upturned lode, with the diffuse gold gradually being mechanically concentrated in the less sloping stream beds below. Some of these placer mines contained ore so rich that a shovelful of it was worth $200 or $300. Here, too, were often unearthed pure gold nuggets of various sizes, to delight the heart of the pioneer prospector. The famous Homestake Mine in the Black Hills of South Dakota is largely placer beds formed in prehistoric times and later buried by a heavy magmatic deposit.



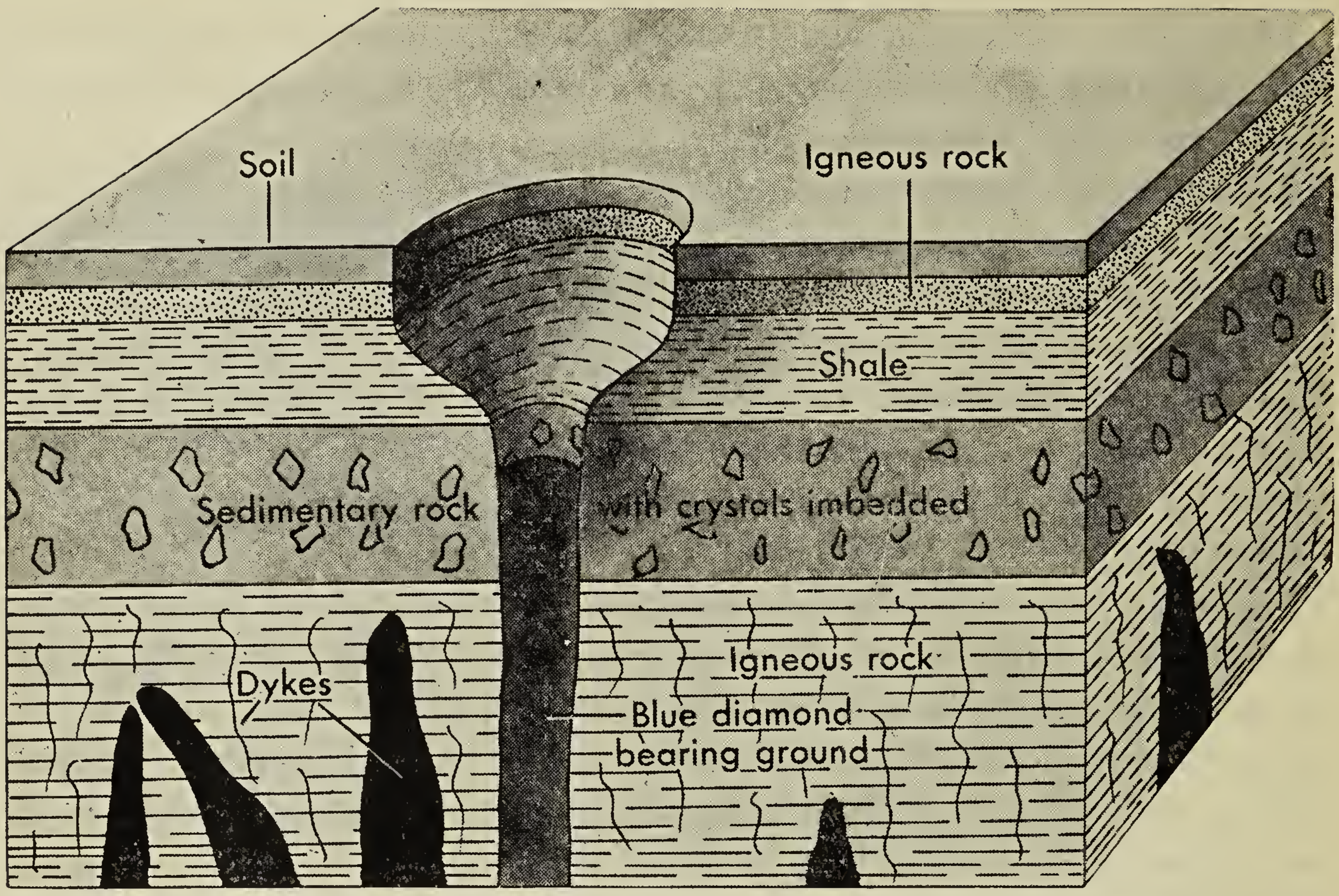
Black Hills Studio

Gold nugget from the Home Stake Mine

Diamonds Are Carbon Products. Among the hundreds of precious and semiprecious stones found in different parts of the world, we shall give diamonds alone a place in this chapter. These gems of nature are selected because of their rather common use as objects of personal adornment and also because of their close association with the most romantic sentiments in human life.

Diamonds are composed of pure carbon in a highly purified and crystallized form. It is difficult to see the similarity between a piece of anthracite and a diamond, or between the "lead" in a lead pencil and one of these precious stones; yet chemists tell us that in so far as these objects are pure carbon they are alike, the main difference being chiefly one of molecular arrangement in the mass. A person breathes out enough carbon every hour to make a diamond weighing a hundred carats and worth a handsome fortune.

Diamonds Were Formed in Volcanic Cores. Diamonds originally were found solely among the solidified igneous deposits that fill the pipes of old volcanoes. It is believed that the carbon from which they were formed crystallized out under the high temperature and more or less stagnant conditions


Soil
Igneous rock
Shale
Sedimentary rock with crystals imbedded
Dykes
Igneous rock
Blue diamond bearing ground

A diagram to show how diamonds are believed to have been formed

existing in these old volcanic necks after the period of eruption. Thus diamonds are a product of true magmatic segregation. Minute, more or less defective, diamonds have been produced experimentally from carbon by the use of high temperatures.

The solidified contents of these ancient volcano pipes are composed of a number of basic minerals, among which the diamonds are found. This igneous rock is of a tough structure and is commonly called *blue ground.* After the blue ground is mined, it is exposed to the weathering action of the atmosphere for a year or so, during which it breaks up so that the diamonds can be picked out. The stones range from minute crystals which are mere specks to an extreme weight of over three thousand carats. The sparkling effect produced by illuminated diamonds is secured by cutting, which has been developed into a very high technical art. The famous Cullinan diamond, mined in the Transvaal of South Africa in 1905, measured four and a half by two and a quarter inches and weighed almost one and a half pounds. It was the largest diamond ever mined, and has been cut into nine large stones and scores of smaller ones. Two of the large stones are the largest gems of this kind in existence and are the prized possessions of the British Crown.

The richest diamond mines of the world are found in South Africa. The Kimberley and Premier mines are the best-known, and each of these has yielded hundreds of millions of dollars' worth of stones. The Premier plug is over half a mile long, and in width exceeds a quarter of a mile.

Diamonds are also found in Brazil. The world's largest diamond from that region, called the President Vargas, weighed a little over 5.1 ounces. It is estimated that the stone when completely cut will have a value of $2,000,000.

Diamonds have been found in the United States in Wisconsin, in Arkansas, and in California. In Arkansas a few small stones have been taken from several volcano cores thrust through the sedimentary deposits of the previously overlying rock. These diamonds are used chiefly for industrial purposes. In California, perhaps two hundred diamonds have been found altogether since the gold-rush days, the largest reported weighing about seven carats. These stones are of good quality, but the small number of them found makes diamond-mining in the areas explored an unprofitable venture.

Soil Is Perhaps the Most Valuable Geological Product. Just "common dirt" is the term in which the average person is likely to think of that great mass of weathered, decomposed, and more or less loose rock mantle that covers the earth. If confronted with the question of its value, he might admit that it forms the substratum in which the farmer plants his field crops or into which the city dweller presses the roots of his flowers and shrubs as he transplants them. But seldom does he give any thoughtful consideration to the real value of the soil.

Yet, despite its lowly origin and humble state, in relation to man the soil transcends in value any other natural resource found on the surface of the earth. Beside it the diamond mines of South Africa or the gold fields of Alaska shrivel into insignificance. For this decayed and apparently inert rock mass is the nourishing breast of all living things—the plant first, then the animal. It was doubtless the appreciation of this great truth that led Joyce Kilmer to refer to the tree as an object

> . . . Whose hungry mouth is pressed
> Against the earth's sweet flowing breast.

So, in our study of the earth as a planet undergoing changes that made life and civilization upon it possible, some consideration must be given to the soil.

Weathered Rock Forms the Basis of Soil. The basis of all soil is disintegrated rock. The forces of nature acted upon the igneous and sedimentary rocks to break them down into small bits, and in this way initiated the first stages of soil-building. Regardless of how finely these rocks of various kinds may be broken up by nature's mills, however, they are not yet soil. The face of the earth might be covered with these tiny fragments to a depth of hundreds of feet, and yet, if this represented the only soil-making material, no golden harvests could be reaped from the farmer's field and not a single tree could lift its leafy arms above the level plain. For although all elements which plants must obtain from the soil are found in this disintegrated rock, they are securely held there by chemical forces. Still other agencies must make their contribution before fertile soil is produced.

Decomposition Is Necessary in Soil-building. The disintegrated rock must be decomposed or changed chemically as the next step in soil-making. In this transition there are many forces involved. The oxygen of the air is an extremely important agent. It unites with the metals in rock to form oxides. Water too combines with minerals to change their constitution. But perhaps the most potent agent of all in promoting rock decay is the carbonic acid derived from the carbon dioxide of the air combined with water. Because of its weight the carbon dioxide tends to settle down next to the earth, which places it in the best position to unite with moisture to form dilute acid. Ordinary air, as the reader will remember, has about three parts of carbon dioxide to ten thousand parts of other gases; but air from the floor of a forest may contain nine parts, and air from the surface of a pasture eighteen parts, of carbon dioxide to each ten thousand parts of air. Plant roots also excrete considerable amounts of this gas.

Small quantities of other acids, such as nitric and sulfuric acids, are brought down from the air by the falling rain, and humic acids of all sorts form as products of decaying vegetation. These agents all attack the surface of rock particles, from the tiniest grain of sand to massive boulders, and gradually transform them into chemical substances necessary to soil. But this disintegrated and decomposed mass is not yet fertile soil.

The Final Stages in Soil-building Involve Lower Organisms. Still other components must be added to decayed rock to form productive soil. Among these are myriads of minute one-celled plants called bacteria. These tiny organisms, by their action, are especially effective in promoting desirable soil changes of all kinds. Soil cannot continue to be productive without them. It has been estimated, on the basis of careful bacteria counts, that fertile soil has from five hundred thousand to ten million bacteria to the gram, or from fifteen million to three hundred million per ounce. From this it may be seen that the upper layer of field soil in good tilth is a seething mass of these unicellular plants.

Fertile soil should also contain considerable amounts of decaying matter, such as leaves, roots, stubble, and the excreta of animals. It is in the decomposition of this mass of organic material, working it over and making it a necessary component of fertile soil, that bacteria are indispensable.

The humble, harmless earthworm too becomes man's benefactor in the process of soil formation. Perhaps the most careful, patient, and persistent student of the activities of earthworms was Charles Darwin. He was so impressed with their prodigious labors and the valuable role which they play in the economy of nature that he wrote a whole book about them. Earthworms live on bits of vegetable humus and other decayed organic matter. In connection with this they swallow relatively large quantities of fine sand grains which are found intermixed with their food. In their gizzards these sand particles become efficient grinding organs that not only wear down the sand grains themselves but reduce the vegetable matter, to which the digestive juices have been added, to a pulp. The part of the food that is not absorbed passes on through the alimentary canal of the worm and finally issues as excreta. Darwin tells us, as a result of most careful observation, that in many places the total amount of these castings brought to the surface and deposited produces a layer two tenths of an inch deep a year. At this rate the total in five years would be a layer one inch deep, or one hundred tons per acre.

Moreover, these worms penetrate the soil with burrows in all directions to a depth of five or six feet. Into these burrows they drag great quantities of leaf bits and other organic matter, which, on decaying, add humus. At the same time they are constantly working and loosening up the soil, admitting air, draining out surplus water, and making passageways for the tiny roots of plants through the compact earth. Darwin states their activities in these words:

> The plow is one of the most ancient and valuable of man's inventions; but long before he existed, the land was in fact regularly plowed, and still continues to be thus plowed by earthworms. It may be doubted whether there are any other animals which have played so important a part in the history of the world, as have these lowly organized creatures.[1]

The action of burrowing animals, insects, ants, and other denizens of the soil also helped to prepare it as a suitable medium for the roots of higher plants. They open it up, admitting air and, if it be a rather tight soil, making it possible for rain water to penetrate down deeply into the subsoil. Such is the long, slow process by which original rocks forming the earth's surface are ground up, added to, and worked over into soil. What a complicated and prolonged process soil-making is and how necessary to the world of living things! Dr. Isaiah Bowman portrays the importance of soil in this appropriate paragraph:

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[1] C. R. Darwin, *The Formation of Vegetable Mould*, p. 313. By permission, D. Appleton and Company, publishers.

> Men whose work brings them into touch with the soil and its relation to life do not employ the phrase "mother earth" in a casual sense. The great hosts of plant and animal life that people the lands in large part have their origin in or draw their support from the cover of land waste whose upper layers are the soil. They are, directly or indirectly, the dependent children of the earth. Viewed from such a standpoint the soil is not mere dirt, a substance to be despised, a synonym for filth, but a great storehouse of energy, a great home, a bountiful mother. Countless billions of microorganisms—the bacterial flora—throng its dark passageways while the roots of countless higher plants ramify through it in eager quest for food and water. Only less numerous are the earthworms, insects, and burrowing animals that delve into it for food as well as for shelter. To supply all these needs is no mean function; it is probable that no other planet in our solar system has so large an endowment of life-giving, life-supporting soil; the evolution of the life of the earth would have been on far lower levels if the endowment had not been so generous.[1]

This is the story of how nature makes the soil. Day and night, year in and year out, the silent forces work. Only after centuries does their finished product—fertile, arable soil—result. What important stuff it is! What innumerable forces have done their bit in its formation! The most valuable of all our natural resources, how men ought to treasure and conserve it!

Questions for Study

1. What are some of the reasons for believing that coal is old and is of plant origin?
2. How has man's increased knowledge of geological activity and the products formed by geological forces served to modify his picture of the world?
3. How does the geologist attempt to explain the formation of the different kinds of coal?
4. How has the discovery and use of petroleum affected modern life?
5. How do geophysicists attempt to discover the location of subterranean oil pools?
6. How do geologists attempt to explain the formation of oil deposits?
7. How would you explain the formation of salt beds located in the state of Kansas?

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[1] Reprinted by permission from *Forest Physiography* by Isaiah Bowman, published by John Wiley and Sons, Inc.

8. How does the geologist attempt to explain the formation of Great Salt Lake and the great salt flats of Utah and Nevada?

9. In what ways has man's increased knowledge of ores and methods of extracting the metals from their ores influenced modern life?

10. How has a knowledge of alloys modified modern life?

11. What are the particular characteristics of diamonds that make them such prized stones?

12. What is soil?

13. What agents are operative in soil-forming?

14. Why can it be said that man is dependent, either directly or indirectly, on the soil for all the things he eats, uses, and wears?

15. How is proper crop rotation related to soil fertility?

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GLOSSARY

aboriginal: existing from the beginning or native to the soil.

absolute temperature: temperature expressed in degrees above the absolute zero.

absolute zero: a temperature at which bodies would possess no heat whatever. Since heat is the kinetic energy of the motions of the molecules of a substance, then at absolute zero a condition exists in which there is no motion of the molecules with respect to one another. It is equal to —273°.

acceleration: the rate of change of the velocity or speed of an object with respect to time.

accretion: growth by external addition.

acid: a compound of hydrogen in which all or a part of the hydrogen may be replaced by a metal or a basic radical, forming a new compound.

adhesion: a term used to designate one of the intermolecular forces tending to hold matter together; generally used to designate the sticking together of unlike kinds of substances.

aërial: (1) relating to the air; (2) the same as antenna.

aggradation: the natural filling up of the bed of a watercourse, at any point of weakening of the current, by deposition of detritus.

alchemy: the immature chemistry of the Middle Ages, characterized by the professed art of changing the common metals into gold.

alimentary canal: the digestive tract through which food is conveyed and through which it is absorbed by the body.

alternating current: a current of electricity which reverses the direction of its flow at regular intervals.

ampere: the practical unit of electric current. The international ampere is 1 international coulomb per second, or that current which will deposit 0.001118 gram of silver in 1 second from a solution of silver nitrate in a coulombmeter under prescribed conditions. It is that current which will flow in an electrical circuit when the resistance is 1 ohm and the emf is 1 volt.

amplifier: a device included in, or attached to, a receiving set which increases the magnitude of radio waves or sound waves.

amplitude: the maximum displacement of a vibrating body. Amplitude of a particle in a wave is the maximum displacement of that particle from its position of rest.

aneroid: not containing a liquid; referring to instruments which do not depend upon any liquid for their operation; as, an aneroid barometer.

anode: the positive pole in an electric circuit; the terminal by which the current enters an electrolyte.

antenna: a wire or wires supported in the air to transmit or to detect electromagnetic waves.

anticyclone: an atmospheric condition of high central pressure, with air currents flowing outward; a high-pressure area.

aphelion: that point in the orbit of a planet or a comet farthest from the sun.

armature: that part of a dynamo which carries loops of conducting wire through the field of a magnet in such a way that when the armature is revolved the wires will cut the lines of force, with the result that a current of electricity is induced in them; or, the corresponding part of a motor, through which electrical current is passed in order that electrical energy may be transformed into motion.

artesian well: a well made by boring into the earth to water, which, under certain geological conditions, is under pressure and consequently rises to the surface.

asphaltum: a brownish-black or black natural mixture of complex hydrocarbons, solid or liquid.

asteroid: one of a great number of small planets whose orbits lie between Mars and Jupiter.

astrolabe: an ancient instrument used for determining the altitudes of planets and stars.

astronomy: the study of the constitution, distances, motions, and controlling laws of the heavenly bodies.

atmosphere: the gaseous envelope surrounding a planet or stellar body.

atoll: an annular island consisting of a reef formed from petrified skeletons of coral and inclosing a central lagoon.

atom: the smallest particle into which matter can be broken up by chemical means. It may be further broken up by physical means into electrons, protons, neutrons, etc.

atomic number: a number assigned to an atom to place it in the periodic arrangement of elements; it is equal to the number of planetary electrons.

atomic weight: a number which expresses the relative weight of a chemical element when 16 is assigned as the weight of the atom of oxygen.

audio-frequency: variations in the intensity of electrical impulses which are of such a nature that they may be made audible through suitable devices such as a loud speaker.

auroral displays: the radiant lights of the polar skies.

bacteria: an important and widely distributed group of microscopic one-celled vegetable organisms.

barograph: an automatic instrument for recording atmospheric pressure.

barometer: an instrument for indicating the pressure of the atmosphere.

basalt: a group of dark, heavy, fine-grained rocks of volcanic origin.

base: a chemical compound which will react with an acid, neutralizing it and forming a salt.

battery: a single cell or a group of cells producing electric current, or potential, by converting chemical energy into electrical energy.

binary stars: a pair of stars revolving around their common center of gravity.

biology: the science which deals with the origin, structure, functions, and life history of vegetable and animal organisms.

calcite: a natural calcium carbonate occurring in many crystalline forms.

calorie: the amount of heat required to raise the temperature of one gram of pure water 1° C.

carat: a unit of weight for jewels: in the United States exactly $\frac{1}{5}$ gram.

carbonation: the chemical combination of carbonic acid with a base, resulting in the production of carbonates.

carbonized: reduced to carbon.

carnivorous: eating or living on flesh.

cathode: the negative pole of an electrolytic cell or of a battery; that pole of an electric source through which the current leaves the electrolyte; the opposite of anode.

celestial: pertaining to the sky or heavens.

centigrade: a thermometer scale having 0° as the freezing point of water and 100° as the boiling point.

centrifugal: moving, or tending to move, away from the center.

centripetal: moving, or tending to move, toward the center.

chemistry: the science which treats of the nature and composition of different kinds of matter and the laws which govern their relationship.

chromosphere: a thin layer of incandescent red gas surrounding the sun. It is invisible to direct vision except at the beginning or the end of a total eclipse.

chronometer: an instrument for measuring time.

coherer: a device formerly used for detecting the signals in wireless telegraphy; supplanted now by the crystal detector and the vacuum tube.

cohesion: a term used to designate one of the intermolecular forces tending to hold matter together. Generally used to designate the forces tending to hold like kinds of substances together.

coma: the head of a comet, so called because it is hazy and nebulous in appearance.

commutator: a device consisting of a number of copper segments assembled around the hub of the armature of a generator which is attached to the rotating shaft. These segments are insulated from the shaft and from each other. They are also connected to the rotatable loops on the armature. Resting on these are brushes, which carry the currents set up in the loops to the external circuit to which the brushes are attached. The function of the commutator is to effect a reversal of the current set up in the armature loops of the generator at the proper point to produce a direct current in the connected circuit. It is also used to introduce current from an external circuit into the armature windings at the proper point in a motor.

concave: an incurved surface; as, the inner surface of a sphere or circle.

concentration: the process of increasing the strength of a solution by the evaporation of liquid or volatile ingredients.

concentric spheres: spheres having a common center.

condensation: a reduction in size; a compressing of particles; as, the change from a vaporous to a liquid form.

condenser: a device for accumulating an electric charge, consisting of two conductors separated by a nonconductor.

conductor: a substance which transmits or is capable of transmitting electricity, heat, sound, or other forms of energy.

conglomerate: a rock composed of pebbles or gravel cemented together.

constellation: a group of stars having a definite arrangement.

convection: the diffusion of heat through a gas or a liquid by a motion of its parts.

convex: an outcurved surface; as, the outer surface of a sphere.

convolution: a coiling, or winding, motion; one of the windings or tortuous folds of an organ.

corona: the radial streams of light which can be seen around the sun during a total eclipse. These produce the effect of a halo.

cosmos: the world, or universe, considered as an orderly arranged system.

crater: the cup-shaped cavity forming the mouth of a volcano or any other similarly shaped opening.

Cro-Magnon: a race of men dating from the Late Glacial Age who used stone and bone implements, though unable to work metals.

crystal: a homogeneous and angular solid of definite form which is characterized by geometrically arranged plane surfaces.

cycle: a period the astronomical events of which recur in the same order in the next period; a series that repeats itself.

cyclic: moving in a circle; recurring in cycles.

cyclone: an atmospheric condition of low central pressure, with air currents flowing inward; a low-pressure area.

decomposition: the process of separating a compound into its original elements by chemical action; natural decay.

density: the mass per unit volume of a substance, usually expressed in grams per cubic centimeter.

detector: any one of several devices for discovering the presence of electric waves.

diffusion: the scattering of the particles of one substance throughout the particles of another substance.

direct current: an electric current flowing in one direction.

dirigible (more properly called **airship**)**:** a type of aircraft which is supported in the air by the buoyant effects of gases which are lighter than air. The lifting gases are contained within the envelope of the airship. The ship is circular in cross section and tapered at the ends, with a ratio of length to diameter of between 5 to 1 and 8 to 1. Propulsion is by means of air propellers driven by internal-combustion engines. Airships are of three classes: nonrigid, semirigid, and rigid.

disintegration: the process of reducing a body to fragments. Physical destruction rather than chemical decomposition.

doldrums: the tropical zones of calms.

double star: close companion stars, most often but not always revolving about a common center in mutual gravitational control.

dynamic: moving, or in a state of constant motion.

eclipse: the total or partial darkening of a heavenly body produced by another heavenly body coming between it and the observer or between it and the source of light.

electricity: an imponderable and invisible agency capable, under different circumstances, of producing light, heat, chemical decomposition, and other physical phenomena.

electrode: either pole, or terminal, of an electric apparatus: when positive, called anode; when negative, cathode.

electrolysis: the process of decomposing a chemical compound by the passage of an electric current through it.

electrolyte: a chemical compound which can be decomposed by an electric current; any substance which produces ions upon going into solution.

electromagnet: a soft-iron core which is temporarily magnetized by the passage of an electric current through a coil of wire surrounding it.

electron: a name given to any negative particle of matter having a charge of 4.77×10^{-10} electrostatic units and a mass of 9×10^{-28} gram, or $\frac{1}{1847}$ that of the hydrogen atom. Recently it has been necessary to modify this concept and recognize that the electron has wave characteristics, with a frequency and a wave length.

elements: a number of substances, or kinds of matter, which are not decomposable by ordinary methods of chemical analysis, and from combinations of which compounds are formed.

ellipsoidal: having the general shape of an ellipse.

elliptical: shaped like an oblong with rounded ends.

emanate: to flow forth or issue as from some source.

embryo: the germ, or rudimentary form, of anything in its earliest development.

energy: the power by which anything acts effectively to move or change other things.

equilibrium: state of balance.

equinox: the name given to each of the two opposite points at which the line of intersection of the plane of the earth's equator with the plane of the ecliptic intersects the celestial sphere. The sun appears to pass through each of these points once each year—on or about March 21 and on or about September 21.

erode: to wear away by various agencies.

ether: a supposed medium filling all space through which radiant energy is transmitted.

evolution: the process of change.

extragalactic: outside our galaxy.

Fahrenheit: a thermometer scale in which at sea level the freezing point of water is 32° and the boiling point is 212°.

fault: a sliding displacement of rock structures along a fracture in the earth's crust.

feldspar: a group of igneous crystalline rock minerals which are chiefly silicates of aluminum with silicates of sodium, potassium, or calcium.

filament: a fine metallic wire in a bulb or a vacuum tube which glows when an electric current of suitable voltage passes through it. The filament in a radio vacuum tube is intended primarily to send out electrons and not to produce light.

filter: a strainer or a purifier; to purify, as a liquid, by passing through some medium that retains the solid impurities.

filtration: the process of separating a solid from a fluid by means of a porous substance through which the fluid passes.

firmament: the expanse of heavens; the sky.

fissure: cracks caused by fracturing.

flora: the native plants of a particular region or period of the earth's history.

fluorescence: the property exhibited by certain liquids and solids of becoming self-luminous when subjected to sunlight, light from the X-ray tube, some source of ultraviolet light, the emanation from radium, or the stream of electrons from the Coolidge tube; the light given off by fluorescent bodies.

focus: the point at which rays of light, sound, heat, etc. meet, or from which they appear to diverge after being reflected or refracted.

force: any cause tending to produce, stop, or change the motion of a body; any operating energy.

fossil: an animal or plant, or any trace or impression of an animal or plant, of prehistoric times.

Fraunhofer lines: the dark lines in the solar spectrum, produced by the absorption of the sun's light by the vapors of various elements present in its atmosphere.

frequency: the number of waves (cycles) produced in a second.

friction: the rubbing together of two bodies; hindrance to motion so produced.

galaxy: a system of stars.

galvanometer: an instrument for measuring electric currents, especially small ones, usually by means of their magnetic effect.

gas: a completely elastic airlike fluid tending to expand indefinitely and possessing the property of occupying the total volume of any vessel in which it exists.

generator: the apparatus by which some desired substance or form of energy is generated or produced.

genesis: the act or process of producing or originating.

geology: the science dealing with the physical history of the earth and the structure of the earth's surface.

geophysics: that part of physics relating to the earth in such matters as the phenomena of tides, magnetism, temperature, and meteorology.

geosyncline: a vast downward flexure of the earth's crust.

geyser: a hot spring which at intervals throws jets of water, mud, and steam into the air.

glacier: a field or stream of ice formed in regions of perennial frost from compacted snow, which moves slowly downward over slopes or through valleys until it either melts or breaks off in the form of icebergs on the borders of the sea.

gradient: having a regular grade or degrees of inclination; rising or descending gently or by degrees.

granite: a hard, crystalline igneous rock consisting of quartz, feldspar, and usually mica.

gravitation: the force which attracts one mass toward another; the force which draws all bodies in the universe toward one another.

grid: the controlling element of a vacuum tube. Usually it consists of a frame of perforated metal between, and insulated from, the plate and the filament of a vacuum tube.

ground: in general, the earth when employed as a return conductor in an electric circuit; a connection of a current with the earth.

hematite: one of the most important ores of iron.

Hertzian waves: electromagnetic waves, first systematically studied by Heinrich Hertz.

heterogeneous: consisting of dissimilar ingredients; not homogeneous.

homogeneous: composed of similar parts; uniform.

horse latitudes: two zones, about 30° north and 30° south of the equator, which are usually marked by an absence of winds and which generally have clear weather.

horsepower: a unit of power equal to that required to raise 33,000 pounds at the rate of 1 foot per minute.

humidity: the relative condition of the atmosphere with reference to its content of water vapor.

humus: decaying plant and animal matter mixed with soil.

hurricane: any gale of extreme and unusual violence.

hydroscopic: having the property of absorbing and condensing moisture from the atmosphere.

hydrosphere: collectively, the total water surrounding the earth. It includes the atmospheric moisture, the oceans, all surface waters, and the underground streams.

hypothesis: a proposition, theory, or principle assumed as a basis for reasoning or to explain certain phenomena.

igneous: formed under intense heat.

image: an optical counterpart of an object formed by rays of light reflected from a mirror or refracted through a lens.

impervious: not permitting penetration.

incandescent: made luminous by heat; white or glowing with heat.

induction: the production of magnetization or electrification in a body by the mere proximity of magnetized or electrified bodies; the production of an electric current in a conductor by the variation of the magnetic field in its vicinity.

inertia: that property of matter by which it tends to remain in its condition of rest or of uniform motion in a straight line except as it is compelled to change that condition by external force applied to it.

inorganic: applied to matter which is not and has not been alive; without physical structure which was produced by life processes.

insolation: exposure to the rays of the sun; irradiation.

insoluble: not capable of being dissolved in a liquid.

insulator: a substance that is a nonconductor of electricity, heat, or sound.

interference: the action of two vibratory motions that tend to neutralize or to augment each other by a combination of opposite or like phases of motion.

interferometer: an instrument for studying the phenomena of the interference of light.

interstellar: relating to, or situated in, the regions of space among the stars.

interstice: an opening in anything or between things.

intrinsic: pertaining to the very nature of a thing or to its real or true value.

intrusion: the forcing of masses of molten rock into or between other rocks.

ion: one of the units formed when a molecule of an electrolyte dissociates (breaks up) on going into solution. An ion may consist of a charged atom or group of atoms. It may be positively or negatively charged.

ionization: the process by which part of the molecules of an electrolyte, as it goes into solution, are separated into smaller units called ions; the process by which some of the molecules of a gas are caused to assume electric charges, so that the gas is capable of conducting an electric current.

island universe: a spiral nebula regarded as a universe similar in scope to our galaxy.

isobar: a line on a chart, globe, or map connecting places having the same barometric pressure.

isostasy: a theoretical condition of equilibrium which the earth's surface tends to assume under the action of terrestrial gravitation, as affected by the transference of material from one region to another deep down in the earth.

isothermal: having or indicating equal temperatures.

isotope: one of two or more closely allied elements having identical chemical properties but differing slightly in atomic weights.

kinetic energy: the energy possessed by a moving body due to its motion.

latent heat of vaporization: the hidden heat required to change a liquid to a gas without an increase in temperature.

latitude: distance on the earth's surface measured northward or southward from the equator; the angular distance of a heavenly body above the plane of the ecliptic as viewed from some point.

lava: melted rock such as that which is thrown from a volcano.

lens: a piece of glass or other transparent substance with one or two curved surfaces, having the property of converging or diverging beams of light and forming images of objects.

Leyden jar: an electric condenser consisting of a glass vessel lined part way up from the bottom, both internally and externally, with tin foil.

light: visible radiations coming from an incandescent source.

light year: the space traversed in one year by a ray of light, which in air travels at the rate of about 186,000 miles per second. It is used as a unit in stating distances of the stars.

limestone: a rock, essentially of calcium carbonate, used in construction, in smelting, and as a source of lime.

lithosphere: the solid portion of the earth.

lodestone: a piece of magnetite, the magnetic oxide of iron, which has magnetic poles and the power of attracting bits of iron or steel; a natural magnet.

longitude: the distance east or west on the earth's surface measured by the angle which the meridian through a place makes with some standard meridian, such as that at Greenwich or Paris.

loud: striking the auditory nerves with great force; having great volume or intensity of sound.

luminous: emitting original light; giving or radiating light.

lunar: of, or pertaining to, the moon.

magma: the molten matter from which igneous rocks are formed or derived.

magnet: a body, as a piece of iron or steel, which has the properties of attracting iron and of taking a definite direction when freely suspended in a magnetic field.

magnetic field: the region near a magnet or electric current where magnetic force is exerted.

magnification: the process of increasing the apparent size of an object.

magnitude: the brightness of a star expressed on a scale in which a star of the sixth magnitude is approximately 100 times fainter than a star of the first magnitude.

mantle rock: the loose fragmental material resulting from the disintegration of the hard rocks and covering the greater part of the earth's surface.

mass: the measure or expression of the quantity of matter in a body as indicated either by its weight or by the amount of force necessary to produce a given amount of motion in the body in a given time (its inertia).

matter: the form of being or substance that is characterized by extension, inertia, weight, etc.

metalliferous: containing or yielding metals.

meteor: a small celestial body that becomes luminous when it meets with the resistance of the earth's atmosphere; popularly called a "shooting star."

meteorite: a metallic or stony mass that has fallen to the earth from outer space.

meteorology: the science that treats of atmospheric phenomena.

meter: the standard unit of length in the metric system. It equals 39.37 inches.

microphone: an instrument used to vary the electric current in a transmitting circuit by means of sound.

Milky Way: a broad, luminous band encircling the heavens, consisting of countless stars not separately visible to the naked eye.

mineral: any nonorganic substance found in nature.

mineralogy: the science of minerals.

molecule: a group of atoms bound together by chemical forces and acting as a physical unit.

moraine: a ridge or heap of rocks and gravel gathered by a glacier and deposited at its edge or base.

motor: a machine that changes other forms of energy into mechanical energy.

mutability: the change of one element into another.

myriad: a vast indefinite number.

nebula: a luminous formation in the heavens resembling a patch of haze and consisting either of a mass of luminous gas or of a cluster of stars too far away to be separately distinguishable.

neutron: a neutral body which has nearly the same mass as the ordinary hydrogen atom.

nucleus: the central or focal portion which serves as the center of growth or development.

oblique: a deviation from the perpendicular; slanting.

ocular: depending on, or as seen by, the eye.

opaque: impervious to light; not transparent.

ore: a natural substance containing a metal.

organic: in biology, pertaining to, or derived from, anything that has life; in chemistry, applied to that branch of chemistry which deals with compounds of carbon.

oscillation: the to-and-fro, or vibratory, motion of an object, a wave, an electron, etc.

oxidation: the process by which oxygen unites chemically with some other substance. Oxidation involves a loss of electrons, which always increases the positive charge on the atom or radical.

oxyhydrogen flame: the burning of a mixture of oxygen and hydrogen, which produces an intense heat.

paleontology: a branch of geology which treats of life in past geological periods, as shown by the evidence of plant and animal remains in fossils.

parallax: the apparent displacement, or difference in direction, of a heavenly body as seen by an observer from two different positions.

pathogenic: productive of disease.

peat: a carbonaceous deposit occurring principally in swamps, composed of partly decayed vegetative matter and forming a valuable fuel when air-dried.

pendulum: a hanging body so supported as to permit it to swing backward and forward, under the influence of gravity, with a minimum of frictional resistance.

percolate: to pass through fine interstices.

perihelion: that point in the orbit of a planet or comet nearest to the sun.

petrify: to convert into stone or to become stony.

petroleum: mineral oil. A native mixture of a solution of gaseous, liquid, and solid hydrocarbons.

phenomenon: in science, any physically observable fact or event.

philosophy: the study and knowledge of principles that cause, control, or explain facts and events.

phosphorescence: the property of continuing to shine in the dark after exposure to light; glowing or giving off light.

photoelectricity: electricity produced or affected by the action of light.

physiography: the descriptive study of the earth and its natural phenomena; physical geography.

pigment: any substance which imparts color.

pitch: that which the normal ear recognizes as corresponding to position in the musical scale. It is primarily dependent upon the frequency of the sound waves.

placer mining: mining by washing loose surface soil, the lighter matter being carried away while the heavier particles of valuable material remain.

planet: any one of the larger heavenly bodies of the solar system revolving around the sun and shining by reflected light.

planetesimal: a celestial body of any size from a molecule up to a planetoid; gravitational meteoritic matter.

planetoid: a small planet; an asteroid.

plate: the output terminal or element of a radio vacuum tube.

plateau: an extensive stretch of elevated and fairly level land.

polarity: the quality, possessed by magnets, of having two opposite poles, or centers of attraction, each exerting a force opposite to that of the other.

polarization: the state of having two poles.

porosity: that general property of matter by virtue of which every substance has between the molecules minute, irregularly shaped spaces called pores, in which the molecules move back and forth.

positron: an elementary charged particle whose mass appears to be of the order of that of the electron and whose charge is positive. It is sometimes called the positive electron.

postulate: to state as a fact.

potential: a term used in physics to denote a number of different quantities all of which are characterized by their connection with potential energy; for example, electrical potential, gravitational potential, and mass potential.

precipitate: an insoluble solid substance formed within a body of liquid by some chemical or physical change.

precipitation: moisture condensed from the atmosphere and falling upon the earth's surface. In chemistry the process by which any substance in solution is made to separate as a solid and settle to the bottom of the containing vessel.

proton: the nucleus (H^1) of the ionized ordinary hydrogen atom. It bears a single positive charge and has a mass equal to the mass of the hydrogen atom minus the electron, or about 1.661×10^{-24} gram.

psychrometer: an instrument for measuring the humidity of the atmosphere.

pyrotechnic: pertaining to fireworks.

quality: an attribute due to the complexity of a musical sound. It is produced by the resultant of the lowest or fundamental note and the several harmonics which may be present in varying relative intensities along with this fundamental.

quantum: an elemental amount, or unit, of radiant energy.

quartz: a natural form of crystallized silica.

radiation: the act of sending out rays or direct lines from a point or surface; the sending out of energy in the form of light or heat, etc.

radical: any group of atoms that passes unchanged through a chemical reaction and behaves as a single atom.

radio: communication by telegraph or telephone without wires connecting the places of transmission and reception, the message being carried in the form of electromagnetic waves.

radioactivity: the property possessed by certain substances, such as radium, etc., of spontaneously emitting special radiations, invisible to the eye, which have specific properties.

radiometer: an instrument for detecting and measuring radiant energy.

reaction: the mutual interaction of chemical agents according to their characteristic properties.

reagent: a substance used to effect a chemical change in another substance.

reduction: a chemical reaction in which oxygen is taken out of a substance. Reduction involves a gain of electrons which always adds to the negative charges carried by the atom or radical.

reflector, or **reflecting telescope:** a telescope in which the rays are received and concentrated toward a focus by means of a concave mirror.

refraction: the change of direction which light waves or other waves experience on passing obliquely from one medium to another in which its velocity of propagation is different.

refractor, or **refracting telescope:** a telescope in which the rays are received and concentrated toward a focus by means of a lens.

refrangible: capable of being bent, or refracted.

relative humidity: the ratio between the water vapor present in the air at a certain temperature and pressure and the amount necessary to saturate it under these conditions.

residue: that which remains after a part has been removed.

resistance: the opposition offered by a body to the passage through it of a current of electricity, resulting in electrical energy being converted into heat.

revolution: the course of a body around another body or around a central point which is considered as fixed; a motion in a closed curve around a center.

Rosetta Stone: a tablet discovered near Rosetta, Egypt, in 1799, bearing inscriptions which first enabled scientists to decipher the ancient Egyptian writings.

rotation: the turning of a body around its axis or center.

saline: the quality of being salty.

salt: a substance that results from the action between an acid and a base; or a compound of a metal or positive radical and a nonmetal or negative radical.

sandstone: a rock composed chiefly of quartz sand and hardened into a solid mass by a natural cement.

satellite: a moon or a small planet revolving about a larger one.

saturated solution: a liquid in which is dissolved the greatest amount of a certain solute that can be retained when an excess of the solid solute is present.

science: knowledge of facts, laws, and proximate causes, gained and verified by exact observation and correct thinking; also, the sum of universal knowledge.

sedimentary rock: rock composed of materials transported from their sources and deposited by water or wind.

segregation: the process of separating ore or mineral from a parent mass.

seismograph: an instrument for recording automatically the time of occurrence, duration, direction, and intensity of earthquakes.

sensitize: to make susceptible to the action of light, X rays, or other radiations.

shale: a fine-grained sedimentary rock of clayey origin, easily split into thin sheets.

silt: a fine earthy sediment carried and deposited by water.

solar: of, or pertaining to, the sun.

solstice: the time of year when the sun is at its greatest declination, either north or south, usually June 21 and December 22.

soluble: capable of being dissolved in a fluid.

solute: a substance that mixes or dissolves in a solvent to produce a solution.

solution: a preparation made by dissolving a solid, liquid, or gaseous substance in another substance, generally a liquid.

solvent: any liquid in or by which a substance (solute) can be dissolved.

specific gravity: the ratio of the density of a substance to that of water.

specific heat: the ratio between the quantity of heat required to raise the temperature of any mass of a given substance any definite amount, and the amount of heat required to raise the temperature of the same mass of pure water that same amount.

spectroscope: an optical instrument for decomposing a beam of light or radiant energy into its constituent parts.

spectrum: a colored image in which the constituents of a beam of light or other radiant energy are separated and spread out according to their wave lengths.

stable: in a balanced condition not readily destroyed; as, an element not readily reacting or a compound not easily decomposed.

star: a celestial body so distant as to resemble a luminous point.

static: in rest or equilibrium as opposed to motion; the interference with wireless radiations produced by atmospheric electric charges or by the presence of other sources of electricity.

strain: the change of shape or size of a body, especially a solid, produced by the action of a stress.

strata: the geological layers of rock composing the earth's crust.

stratosphere: the isothermal layer of the atmosphere which lies above the troposphere.

stress: the quantitative expression of a condition within an elastic material due to deformations brought about by external forces, such as an applied force or temperature.

subatomic: smaller than the atom.

subterranean: below the surface of the earth.

sun spot: one of the dark patches visible on the sun.

superstition: a belief, act, or practice based on a fear of, or reverence for, the unknown, mysterious, or supernatural.

suspension: a mixture of finely divided particles in a liquid. The particles are so small that they do not settle out.

synchronize: to cause to agree in time, speed, or rate of vibration.

talus: a sloping heap of weathered, disintegrated rock at the foot of a cliff.

temperature: the degree of heat or cold as measured by the thermometer.

terrestrial: of or pertaining to the earth or land.

terrestrial magnetism: the magnetic properties of the earth considered as a whole.

theodolite: an instrument for measuring horizontal and vertical angles in determining distances.

theory: a tentative statement of a supposed principle or relationship advanced to explain facts as observed.

thermal: pertaining to heat or temperature.

thermocouple: an instrument for determining an amount of radiant energy electrically.

thermograph: a thermometer with a device for recording automatically the successive temperatures in a given period.

topography: the science which treats of the surface features of the earth.

tornado: a violent, destructive rotary storm accompanied by whirls of wind produced from a dark funnel-shaped cloud.

trade wind: a wind in or near the torrid zone which blows steadily in the same course, toward the equator.

transformer: a mechanical device for changing the voltage of an alternating current. If used to raise voltage, it is called a step-up transformer; if used to lower voltage, a step-down transformer.

troposphere: the lower layer of the atmosphere immediately surrounding the earth and extending to an altitude of about seven miles.

tuning: changing the capacity, or inductance, in a radio receiving circuit so that the circuit will be in resonance with the frequency of a transmitted radio wave.

typhoon: a violent cyclonic storm usually occurring in the tropical regions.

unicellular: consisting of, or having, one cell only.

universe: the whole system of existing material things.

unstable: easily thrown out of balance or adjustment.

vacuum: a portion or region of space entirely empty of matter.

vacuum tube: a tube used for producing, detecting, or amplifying electrical oscillations or for rectifying an alternating current; also a type of photoelectric cell.

valence: the capacity of an atom or radical to combine with other atoms, as compared with that of hydrogen. This is determined by its capacity to give up or receive electrons.

variable stars: stars which appear to be changing in brightness.

variation: a deviation from the mean orbit of a heavenly body, occasioned by the attraction of another heavenly body.

velocity: the time rate of change of position.

volatile: of such a nature as to evaporate rapidly.

volt: a unit of electromotive force and potential difference. It is the potential or pressure which, if steadily applied to a conductor of one ohm resistance, will produce a current of one ampere.

voltaic cell: a device for producing electrical energy by chemical action.

volume: the amount of space occupied by a body.

volumetric: pertaining to measurement in volumes.

wave length: the distance between corresponding points in two adjacent waves.

weather: the state of the atmosphere as to temperature, humidity, and air movements.

weathering: the wearing away by the various forces of erosion.

weight: the weight of an object is the measure of the earth's gravitational pull for it.

X ray: a form of radiant energy; same as Röntgen rays.

zone of flowage: the portion of the earth's crust below the depth at which the strength of the rocks is exceeded by the weight of the overlying material, and the rocks are therefore rendered plastic by pressure.

zone of fracture: the earth's crust to a depth of eleven or twelve miles.

INDEX

Absolute temperature, 283
Absorption spectrum, 32 f.
Acids, 210 f., 221 ff.; dibasic, 223; hydroxy, 223; organic, 222 f.
Adsorption, 232
Age of earth, 42, 563 ff.; methods of determining, 564 f.
Agents of erosion, 514, 526 ff.
Air, 470 ff.; circulation of, 474 ff.; pressure of, 474 ff., 484 f.; relation of, to weather, 470 f.; water vapor in, 477 f.
Air-conditioning, 309 ff.
Air mass, 484 f.
Airplane, 416 ff.
Alcohols, 221 ff.
Aldehydes, 222
Aliphatic compounds, 224 f.
Alloys, 245 ff.; non-ferrous, 247 ff.
Alpha particles, 145, 147, 160 ff.; nature of, 145; speeds of, 145
Alternating current, 340 ff.
Altimeter, 422 f.
Aluminum, 244 f.; alloys of, 247 f.
Ampere, 335, 341
Amplitude, 439
Ancients, ideas of, 3 f.
Anderson, E. O., 153 f.
Andromeda, 53, 60 ff.
Angstrom unit, 415
Animals, agents of erosion, 523 f.
Anode, 138
Antares, 45
Arc lamps, 412 f.
Arc welding, 445 f.
Archimedes' principle, 182
Aristarchus's theory, 6 f., 16
Aristotle, 14, 18
Armature, 341
Aromatic compounds, 225 f.
Arrhenius, 8, 195 f.
Artificial disintegration, 149 f.
Artificial radioactivity, 151 f., 160 ff., 165 ff.; uses of, 166 f.
Artificial textiles, 253 ff.
Asphaltum, 574 f.
Astrology, 7, 9
Atmosphere, 449 ff., 470 ff.; circulation of, 474 ff.; composition of, 450 f.; development of, 449; extent of, 450; highs in, 484 f.; importance of, 449; knowledge of, 454 ff.; lows in, 484 f.; pressure of, 180, 450; strata of, 460 f.; structure of, 456 f.; temperatures in, 452 f.
Atom, 137 f., 155 f., 168 f.; definition of, 137; size of, 156; space in, 156 f.; structure of, 43 f., 75, 137 f., 148 f., 151 f., 163 f., 198 f.; old theory of structure of, 155; transmutations of, 166 f.
Atomic nucleus, 151, 153 f., 160, 163; size of, 156
Atomic number, 163 f.
Atomic weight, 163 f.
Aurora borealis, 463 f.
Automobile, 300 ff.

Babylonians, 88
Bakelite, 262
Basalt, 503, 516
Basaltic sphere, 503 f.
Basement complex, 500 f., 502 f., 516; composition of, 516
Bases, 212 ff.
Battery, 332 f., 359 ff.; storage, 359 ff.; voltaic, 332 f.
Beats, 441
Becquerel, 143 f.
Benzene ring, 225 f.
Bergwerk, 577
Beryllium, 153
Beta particles, 145 f.; nature of, 145 f.
Betelgeuse, 44 f.
Black, Joseph, 274
Blast furnace, 242 f.
Block mountains, 556
Blue ground, 582
Bohr, 155, 366 ff.; atom, 366 f.
Boyle's law, 174
Bright-line spectrum, 32 f.
Bronze, 242
Buoyancy, principle of, 182

Calendar, 132 f.

Caloric, 274, 278 f.
Calorie, 274
Carbohydrates, 250
Carbonations, 525
Carbon dioxide, 451
Carbon transmitter, 357
Carboxyl radical, 223
Catalysis, 208 ff.
Catalytic agent, 209
Cathode, 138 ff.
Cathode rays, 139 f.
Cellulose, 254
Cement, 238
Chadwick, 149, 150, 152 f.
Changes in state, 176
Charles's law, 174 f.
Chemical affinity, 194
Chemical agents of erosion, 524 f.
Chemical changes, 192 ff.
Chemical compounds, 193 f.
Chemical equations, 193
Chemical formulae, 193
Chemical reactions, 194, 205 f.; rate of, 208 f.
Chloroplasts, 267
Chromosphere, 71
Cloud chamber, 154
Clouds, 478
Coal, 251, 268, 271, 569 f
Cobalt, 318
Coherer, 379 f.
Cohesion, 173
Coil, induction, 345 f.
Cold front, 485
Colloids, 227 ff.; hydrophylic, 233; protective, 234
Color, 370 f., 372 f., 374
Comets, 114 ff.; composition of, 120 f.; density of, 116; disintegration of, 116 f.; nature of, 114 f.; number of, 114; occurrence of, 114; orbits of, 114 f.
Common year, 133
Commutator, 342 f.
Compass, 316 f.
Composition of stars, 43 ff.
Composition of sun, 71 ff.
Compounds, 193, 210 ff.; kinds of, 211 ff.; organic, 218
Compression of gases, 180 f.
Condenser, 327
Conduction, 285 ff., 287
Conductivity, 287
Conductors, 328 f.
Conglomerates, 518
Constellations, 37
Continental floors, 499
Continents, formation of, 499 ff.
Contraction, 281 ff.
Convection, 285 ff.
Convection currents, 284 f.
Copernican theory, 15 ff., 88, 103
Copernicus, 12, 15 f., 65, 88, 103
Copper, 242, 244
Corona, 71, 109
Cosmic rays, 153, 371 f.
Cottrel process, 231
Count Rumford, 279
Covalence, 200 f.
Cracking of petroleum, 251
Critical temperature, 306
Crookes, 138
Crookes tube, 138 ff.
Crustal movements of earth, 547 f.
Crystal structure, 196 f.
Curies, 145 f.
Current electricity, 321, 329, 332 ff.; induced, 343 ff.
Cyclotron, 160 f.

Dark-line spectrum, 32 f.
Davy, Sir Humphry, 338
Decibel, 444
Decomposition, 524
De Forest, Lee, 385
Degradation, 521
De-icer, 420
Democritus, 6, 20
Deuterons, 162, 166
Dew, 478
Dialysis, 227
Diamonds, 581 f.; formation of, 581
Diesel engines, 298 f.; fuel-ignition system of, 299
Diffuse nebulae, 58
Diffusion, 178 f.
Direct current, 342
Disintegration, 522
Disperse phase, 227
Dispersion phase, 227
Dissociation theory, 195 f.
Dog star, 128
Dome mountains, 556
Doppler effect, 39 f., 48, 440
Dry cell, 333 f.
Dyes, 251, 253

Earth, 42, 88, 542, 563 ff., 507 ff.; age of, 42, 542, 563 ff.; density of, 46, 512; radial profile, 507 f.; structure, 510 f.
Earthquakes, 548 ff.
Echoes, 435 ff.
Eclipse, 102, 108 f.; causes of, 108 f.; of moon, 102, 109; of sun, 108 f.
Edison effect, 384 f.
Edison, Thomas, 410
Elastic-earth theory, 547
Electric current, 321, 329; nature of, 146
Electric generator, 339 ff.
Electric motor, 351 ff.
Electrical resistance, 341, 348 f.
Electricity, 322 ff., 332 ff.; by chemical action, 332 f.; generation of, 332 f.; heating effect of, 348 f.; kinds of, 332 f.; static, 322 ff.
Electrolysis, 195
Electrolytes, 196 f.
Electromagnet, 322, 335 f.
Electromagnetism, 322
Electromotive force, 340 f.
Electron, 43, 82, 146, 150 ff., 198 f., 326; charge on, 150 f.; effects of, 138 f.
Electrons, orbits of, 156 f.; sharing of, 200; shift of, 324, 368; size of, 156
Electron shells, 200
Electron valve, 385
Electroplating, 197 f.
Electrovalence, 200
Elements, 147, 149 f., 193; numbers of, 163; periodic arrangement of, 202 f.; transformations of, 43, 149 f.
Emission spectrum, 32
Emulsions, 228
Energy, 22, 74 f., 84, 137 ff., 150 f., 272, 370 ff.; from the sun, 74 f. 84 ff.; kinetic, 272; potential, 272; radiant, 22, 370 ff.; states of, 272 f.
Engines, 291 ff., 296 ff.; internal-combustion, 296 ff.; steam, 291 ff.
Enzymes, 210
Equations, chemical, 193
Eratosthenes, 6
Erg, 271
Erosion, 526 ff.; by animals, 523; by chemical action, 524 f.; by heat, 522; by plants, 523 f.; by water, 517, 527 f.; by wind, 533 f.
Esters, 223 f.
Ethane, 219
Ether, 137
Evaporation, 176
Expanding universe, 64
Expansion, 281 ff., 522; of gases, 180 f.
Extrusions, 500

Facsimile transmission, 396
Falling bodies, laws of, 19
Faraday, Michael, 338
Fats, 221
Fault mountains, 556 f.
Faulting, 556 f.
Faults, 549, 561
Fixation of nitrogen, 236
Fixed stars, 37
Flotation process, 232 f.
Flowage, 540 f., 545
Fluids, 177 f.; and transportation, 187
Fluorescent lights, 413 f.
Fog, 478
Folded mountains, 558 ff.
Formulae, meaning of, 193
Fossils, 518
Fraunhofer lines, 38 f., 69; shift of, 38
Frequency modulation, 392 f.
Frosted foods, 306 ff.
Fuse plugs, 348
Fusion, heat of, 276

Galaxy, 51 ff.; composition of, 51; motions of, 53; numbers of, 50 f.; shape of, 52; size of, 51
Galileo, 17, 18 ff.
Galileo's telescope, 19 f., 23
Galvanometer, 332
Gamma rays, 145, 167, 371
Gas laws, 174 f.
Gases, 173, 180 f.; compression of, 180; expansion of, 180
Gasoline, 220, 251
Gay-Lussac, 174
Gels, 229
Generators, electric, 339 ff.
Geologic changes, 499 ff.
Geosyncline, 558 f.
Gilbert, William, 316 f.
Glacial drift, 514
Glaciers, 531 f.
Glass, 239 ff.
Gradation, 520 f.
Granite, 516
Gravitation, 94, 97 ff.; force of, 101 f.
Gravity, specific, 182
Greek idea of universe, 5 ff.
Grid, 385 f.

Grid leak, 387
Gyropilot, 424 f.

Hail, 478
Halley's comet, 103
Heat, 42 f., 173, 208, 274 ff., 348 f., 522; effect of, 208; form of energy, 173; from electricity, 348 f.; from sun, 42 f.; latent, 274 ff.; nature of, 173, 279 f.; of fusion, 276; of stars, 40, 42 f.; source of, on stars, 42 f.; specific, 277 f.; transmission of, 285 ff.; uses of, 291 ff.
Heat capacity, 277
Heating effect of sun, 74 f.
Helium, 33, 139, 147, 152; discovery of, 33
Helmholtz, 42
Heraclides, 6
Hertz, Heinrich, 378
Highs, 484 ff.
Horoscopes, 8, 10
Humidity, 310 f., 477 ff.; absolute, 477; relative, 477
Humus, 585
Huygens, Christian, 363
Hydrations, 525
Hydraulic brakes, 186
Hydraulic press, 181
Hydrocarbons, 219
Hydrogen, 150 f., 210; ions of, 211
Hydrophylic colloids, 233
Hydrosphere, 451, 464 ff.; development of, 464; extent of, 465
Hydrostatic pressure, 178 f.
Hydroxy acids, 223

Iconoscope, 400 f.
Igneous rock, 514 f., 577
Incandescent lamp, 410 f.
Induced charges, 326
Induced currents, 343 ff.
Induction coil, 345 ff.
Inertia, 100
Infrared, 370
Insulators, 328 f.
Interference, 364
Internal-combustion engine, 296 ff.
International date line, 131 f.
Intrusions, 500
Ionization, 196 f.
Ionosphere, 82, 461 f.
Ions, 196 f.
Iron, 242, 317; alloys of, 245 ff.
Island universes, 63; motions of, 63 f.
Isobars, 487
Isostasy, 545 ff., 563
Isotherms, 487
Isotopes, 163 f., 166, 270 f.

Joliots, 165
Jupiter, 20, 88, 107; moons of, 20, 107

Kerogen, 572
Ketones, 224
Kilowatt, 349
Kinescope, 405
Kinetic energy, 272 f.
Kinetic theory of matter, 173
Kirchhoff, 32

Laplacian hypothesis, 103 f.
Latent heat, 274 f.; of vaporization, 275 f.
Lava, 503, 516
Law of gravitation, 98 ff.
Laws of motion, 97 f.
Leap year, 132 f.
Leyden jar, 327
Light, 22 f., 74, 116, 363 ff., 370 ff., 373, 375 f.; absorption of, 373; chemical changes produced by, 23; intensity of, 74; origin of, 22; photoelectric effect of, 375 f.; repellent force of, 115 f.; properties of, 22; rays of, 115 f.; reflection of, 22, 373 f.; refraction of, 22; scattering of, 374; speed of, 370; visible, 370 ff., 472 f.
Light year, 40
Lightning, 325 f., 330 f.
Lightning rods, 330 f.
Lime, 237 f.
Limestone, 518 f.
Liquids, 175 f.; nature of, 175
Lodestone, 316, 320
Loess, 536
Longitude, 129
Loudness, 438 f.
Lows, 484 ff.
Lucite, 262

Magma, 515, 577
Magnesium, 245
Magnetic field, 318, 321
Magnetic lines of force, 318, 340
Magnetic poles, 318 f.
Magnetic storms on sun, 80
Magnetism, 316 ff.; theory of, 335; due to electric current, 321

Magnitude of stars, 44 f.
Mantle rock, 514
Marble, 520
Marconi, 380
Mars, 88, 110 f.
Matter, 137 ff., 150, 160 ff., 173 ff.; atom of, 137; common composition of, 140; early ideas of, 137; energy concept of, 150 f., 155 f.; kinetic theory of, 173; nature of, 138 ff.; states of, 173, 176; structure of, 150 f., 160 ff.
Mendeléeff, 203
Mercury, 88
Mesotron, 155
Metallic ores, 577 ff.; concentration of, 578 ff.
Metals, 242 ff.; alloys of, 245 ff.
Metamorphic rock, 514, 519 f.
Metamorphism, 500 f.
Meteorites,[1] 117 ff.; composition of, 119 ff.; effects produced by, 121 f.; number of, 119, 121; size of, 121 f.
Meteors, 117 ff.; nature of, 118; number of, 119; orbits of, 119; origin of, 118 f.; showers of, 118 f.
Methane, 219
Milky Way, 20, 51 f.
Millikan, Robert A., 153 f., 169
Modulation, 389 f.; frequency, 392 f.
Molecules, 168 f.; speeds of, in air, 174; stability of, 169
Moon, 92 ff., 127; distance to, 69; nature of, 20; phases of, 127
Moons of Jupiter, 20, 107; formation of, 107
Moraines, 532
Moseley, 163; work of, 163
Motion, laws of, 97 f.
Mountains, 552 ff.; block, 556; dome, 556; fault, 556 f.; folded, 558 ff.; residual, 555 f.; volcanic, 553 f.
Mount Palomar, 27 ff.
Mount Wilson, 62, 78
Movement of celestial bodies, 101 f.
Multiple stars, 46 f.
Musical sounds, 438 ff.

Nebulae, 29, 57 ff., 60 f.; extragalactic, 60 ff.; types of, 58
Negative catalyzer, 209
Neon, 139
Neptune, 88, 91 f.
Neutralization, 212
Neutrino, 155
Neutron, 153, 154, 160, 163, 166, 198
Newton, Sir Isaac, 24, 97
Newton's laws of motion, 97 f.
Nickel, 318
Nitrogen, 450 f.
Nitrogen fixation, 236 ff.
Nonelectrolytes, 197
Northern lights, 80
Novae, 49
Nucleus, 43, 151, 155 ff., 160, 163, 198; artificial disintegration of, 160 ff.; mass of, 160; size of, 156
Nylon, 256 f.

Oceans, 465 ff.; composition of, 466; formation of, 465; pressure in, 466 f.; temperature of, 466 f.
Ohm, 348
Oil dome, 573 f.
Oil wells, 573 f.
Ores, 577, 578 ff.; concentration of, 578 ff.; metallic, 577 f.
Organic acids, 222 f.
Organic compounds, 218 ff., 250 ff.
Oscillator, 388 f.
Oxidations, 214 ff.
Ozone, 460

Paper, 257 ff.
Papermaking, sulfite process of, 258
Paraffin series, 220 f.
Pendulums, 282 f.
Peneplain, 562
Periodic arrangement of the elements, 163 ff., 202 f.
Permanent magnetism, 319 f.
Petroleum, 250 f., 572 ff.; deposits of, 573 f.; products of, 250 f.
Petroleum wells, 573
Photoelectric cell, 397 ff.; uses of, 398
Photoelectric effect, 375, 397
Photography, 22, 30
Photons, 365 f.
Physical changes, 192
Pilot balloons, 455
Pitch, 439
Planes of discontinuity, 510
Planetary nebulae, 58
Planetesimal hypothesis, 105 ff.
Planets, 88 ff., 105 ff.; density of, 88; formation of, 105 ff.; groups of, 88; life on, 109 f.; light from, 90
Plants as agents of erosion, 523 f.

Plastics, 262 f.
Plate modulation, 389
Plateaus, formation of, 563
Pluto, 88, 106
Polonium, 153
Positron, 154, 165
Potential, electric, 341
Potential energy, 272 f.
Precipitation, 451, 478 f.
Pressure, 174, 178, 180; atmospheric, 180; definition of, 174; hydrostatic, 178 f.; of gases, 174
Primary coil, 344
Prime meridian, 129
Protective colloids, 234
Protons, 152, 154, 162 f., 198
Prout hypothesis, 149
Ptolemaic theory, 10 f.
Ptolemy, 10 f., 15 f., 20, 65
Push waves, 508

Quality of sound, 440 f.
Quanta, how produced, 366 f.; properties of, 368 f.
Quantum, 366 f.
Quantum theory, 366 f.

Radial profile of earth, 507 f.
Radiant energy, 22, 363 f., 370 ff., 372 ff., 398; application of, 378 ff.; waves of, 370 ff.
Radiation, 285 ff.
Radiations, 22, 74, 155, 285 ff., 288, 372 f.; and atomic structure, 155; infrared, 22; solar, 74; ultraviolet, 23; visible, 372 f.
Radical, 195
Radio, 83, 370, 378 ff., 382 ff., 386 ff., 388 ff., 422, 424; reception of, 386 f.; transmission of, 388 f.; tuning of, 382 f.; uses of, 394 f.
Radio beams, 392 f.
Radio ceilings, 461
Radio waves, 83, 370, 378 f.
Radioactivity, artificial, 165 ff.
Radiosondes, 456
Radiotelegraph, 380 f.
Radium, 145 ff., 166; disintegration of, 147; emanations of, 145 f.; half-life period of, 147; nature of, 145; particles of, 145
Rain, 478
Ramsay, Sir William, 33, 145
Rayon, 253 ff.
Red giants, 44 f.
Reduction, 214 ff.
Reflecting telescopes, 23 ff.
Reflection, 22, 434; of light, 22; of sound, 434
Refracting telescopes, 23 ff.
Refraction of light, 22
Refrigeration, 304 ff.
Relative humidity, 477
Residual mountains, 555 f.
Resins, 262
Resistance, electrical, 341, 348 f.
Resonance, 441 f.
Reverberations, 435
Rock veneers, 502 f.
Rocks, 502 f., 516 f.; basic, 502 ff.; kinds of, 502 f.; sedimentary, 502 f., 516 f.
Röntgen, 140 f.
Rubber, 259 ff.
Rumford, Count, 279
Rutherford, Ernest, 145, 149, 154

Salinity of oceans, 465
Salt, 575
Salt beds, 576 f.
Salts, 213 f.; acid, 214; basic, 214; neutral, 214
Sandstone, 518
Saponification, 224
Satellites, 92 ff.
Saturated compounds, 219
Saturated solutions, 205
Saturn, 88; rings about, 20, 103 f.
Scientific method, rise of, 14
Seasons, causes of, 470 f.
Secondary coil, 344
Sedimentary rock, 516 ff.
Seismograph, 436 f., 508 f.
Shake waves, 508
Shale, 518
Silurian period, 576
Sirius, 46, 128
Slate, 519
Snow, 478
Soddy, Frederick, 145
Soil, 583 ff.; basis of, 583; building of, 584 f.
Solar radiation, 267
Solar system, 42, 88 ff., 103; age of, 42; formation of, 103
Solids, nature of, 189 ff.
Sols, 229
Solstice, 128
Solute, 206
Solutions, 205 ff.
Solvent, 205
Sound, 433 ff., 438 ff.; amplitude of, 439;

beats of, 441; Doppler effect of, 440; loudness of, 438 f.; musical, 438 ff.; nature of, 433; persistence of, 435; pitch of, 438 ff.; quality of, 438, 440 f.; reflection of, 434; resonance of, 441 f.; uses of, 443 f.
Sounding balloons, 455
Specific gravity, 182
Specific heat, 277 f.
Spectroscope, 20, 30 f., 69; principle of, 30 f.
Spectrum, 31, 32 f., 368 ff., 373; absorption, 32 f.; bright-line, 32; dark-line, 32; definition of, 31; electromagnetic, 369 f., 373; emission, 32; of elements, 32
Standard time, 129 f.
Stars, 29, 37 ff., 44 f., 54, 111; brightness of, 49; clusters of, 54; collisions of, 54 f.; composition of, 43 ff.; density of, 46 f.; distance to, 40; fixed, 37; groups of, 43 ff.; heat from, 42 f.; life on, 111; magnitudes of, 49; mass of, 45 f.; motions of, 37; multiple, 46 f.; orbits of, 47 f.; sizes of, 43 ff.; speeds of, 38; systems of, 29; temperatures of, 40, 42 f.; theory of, 42; types of, 43 ff.; variable, 47 ff.
States of matter, 173, 176
Static electricity, 322 ff.; nature of, 322; theory of, 323 f.
Static suppressor, 422
Steam engines, 291 ff.
Steam turbine, 295 f.
Steel, 245 f.
Stethoscope, 438
Storage battery, 359 ff.
Stratosphere, 453, 461
Subatomic changes, 270 f.
Subatomic energy, 270 f.
Sublimation, 190
Substitution, 221
Sun, 20, 42, 53, 68 ff., 127, 267 ff.; chromosphere of, 71; composition of, 71 ff.; corona of, 71; distance to, 68; energy from, 74 f.; heat from, 43, 74 f.; nature of, 69 f.; rotation of, 20; size of, 68, 76; source of energy on, 75, 84 ff., 267; as source of power, 84; temperature of, 69 ff.
Sunspots, 20, 69, 76 ff.; causes of, 76 f.; effect of, on earth, 78 ff.
Supernovae, 48 f.
Surface of discontinuity, 485
Surface tension, 176 f.
Surface wave, 509
Suspensoid, 228
Sympathetic vibrations, 442
Syntony, 382

Talus, 523
Telegraphy, 353 f.; 380 f.; wireless, 380 f.
Telephone, 355 f.; wireless, 378 ff.
Telephone receiver, 358
Telephone transmitter, 357
Telescope, 19, 23 ff.; Galileo's, 19; Lord Rosse's, 24; Mount Palomar, 27 ff.; Mount Wilson, 62; reflecting, 24 ff.; refracting, 23 ff.; theory of operation of, 22 f.
Teletypewriter, 355
Television, 375, 398 ff.; future of, 406 ff.; theory of, 398 f.
Temperature, 40, 69 ff., 206, 522 f., 540; of earth strata, 540; effects of, 206, 281 f.; of stars, 40, 42; of sun, 69 ff.
Terrella, 317
Textiles, artificial, 253 ff.
Thermal conduction, 286 f.
Thermal convection, 285 f.
Thermal radiation, 288 f.
Thermocouple, 33, 35 f.
Thermostat, 282
Thomson, Sir J. J., 140
Time, 5, 127 ff.; ancient ways of reckoning, 127 f.; by moon, 127; by sun, 127 f.; calendar, 132 f.; Egyptian ways of reckoning, 127 f.; modern ways of reckoning, 129 ff.; standard, 129 f.; tropical, 133
Tornadoes, 481 f.
Transformer, 344 f., 345 ff.
Transmutations, 143 ff., 150 ff., 166
Transparency, 374
Transportation, 526 ff.
Troposphere, 460, 473 f.
Tuning, 382
Turbines, steam, 295 f.

Ultraviolet, 82, 371, 413
Ultraviolet lamps, 413 ff.
United States Weather Bureau, 480, 490 ff.
Universe, reasons for study of, 5; Greek ideas of, 5
Uranium, 143 ff., 147, 270 f.
Uranus, 88

Vacuum tubes, 384 ff.; parts of, 386; theory of, 384; uses of, 386 ff.
Valence, 194, 198 ff.; definition of, 194; meaning of, 194; theory of, 198 ff.
Vaporization, 175, 275 ff.; latent heat of, 275 ff.

Variable stars, 47 f.
Venus, 88, 110; description of, 110; phases of, 20
Vertical sections of earth, 544
Viscosity, 184 ff.
Visible nebulae, 58
Visible radiations, 372 f.
Volcanic mountains, 553 f.
Volt, 341
Voltaic cell, 333 f.

Warm front, 485
Water, 465 f., 478, 517, 527 f.; of guttation, 478
Water cycle, 465 f., 479
Water vapor, 477 ff.
Watt, 349
Watt, James, 292
Wave length, 370 ff., 382 f.; and color, 370 ff.; of light, 363 ff.; of radio, 382 ff.; of sound, 382, 433 ff.
Wave theory of light, 364 ff.
Weather, 470 ff.; causes of, 474 f.; factors influencing, 475, 477; high pressure and, 484 f.; in troposphere, 473 f.; low pressure and, 484 f.; observations of, 454 ff.; superstitions about, 472; water vapor and, 477 f.
Weather Bureau, 480, 490 ff.
Weathering, 522 f., 533 ff.; by animals, 523 f.; by chemical action, 524 f.; by contractions, 522; by expansion, 522; by heat, 522; by plants, 523; by temperature, 522
Whirlwinds, 481 f.
White dwarfs, 45
Wilson cloud chamber, 154
Wind, 533 f.
Wireless telegraph, 380 f.
Wireless telephone, 378 ff.
Wright brothers, 416 f.

X rays, 140 ff., 167, 196, 371; discovery of, 140 f.; production of, 141; uses of, 142 f.

Young, Thomas, 364

Zeeman, 77
Zinc, 244
Zodiac, 9 f.
Zone of fracture, 542
Zones, 470 f.
Zymase, 210

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